AERONAUTICS

FIRST ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITT
FOR AERONAUTICS

1915

FIFTH EDITION

WASHINGTON
GOVERNMENT PRINTING OFFICE
1917

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SUBMITTED BY MR. LODGE.

IN THE SENATE OF THE UNITED STATES,
January 31, 1916.

Resolved, That the report of the National Advisory Committee for Aeronautics, transmitted with the President's message of December fifteenth, nineteen hundred and fifteen, be printed as a Senate document, together with the accompanying appendices and illustrations.

Attest:

JAMES M. BAKER,
Secretary.

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REPORTS.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

LETTER OF SUBMITTAL.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
STATE, WAR, AND NAVY BUILDING,
Washington, D. C., December 9, 1915.

The PRESIDENT:

In compliance with the provisions of the act of Congress approved March 3, 1915 (naval appropriation act, Public, No. 273, 63d Cong.), the National Advisory Committee for Aeronautics has the honor to submit herewith its annual report for the period from March 3, 1915, to June 30, 1915, including certain recommendations for future work and a statement of expenditures to June 30, 1915.

The committee was appointed by the President on April 2, 1915, and held its first meeting for organization on April 23, 1915. On June 14 the President approved rules and regulations which had been formulated by the committee for the conduct of its operations.

By the act establishing the committee an appropriation of $5,000 a year for five years was made immediately available. Of the appropriation for the first year, ending June 30, 1915, there was expended a total of $3,938.94, as shown by the itemized statement in the accompanying report, and the unobligated balance of $1,061.06 was covered into the Treasury as required by law.

In order to carry out its purposes and objects, as defined in the act of March 3, 1915, the committee submits herewith certain recommendations and an estimate of expenses for the fiscal year ending June 30, 1917. The estimates in detail were submitted through the Secretary of the Navy.

Attention is invited to the appendixes of the committee's report, and it is requested that they be published with the report of the committee as a public document.

It is apparent to the committee that there is a large amount of important work to be done to place aeronautics on a satisfactory foundation in this country. Competent engineers and limited facilities are already available and can be employed by the committee to advantage, provided sufficient funds be placed at its disposal, as estimated for the fiscal year 1917.

What has been already accomplished by the committee has shown that although its members have devoted as much personal attention as practicable to its operations, yet in order to do all that should be done technical assistance should be provided which can be continuously employed. There are many practical problems in aeronautics now in too indefinite a form to enable their solution to be undertaken. The committee is of the opinion that one of the first and most important steps to be taken in connection with the committee's work is the provision and equipment of a flying field together with aeroplanes and suitable testing gear for determining the forces acting on full-

sized machines in constrained and in free flight, and to this end the estimates submitted contemplate the development of such a technical and operating staff, with the proper equipment for the conduct of full-sized experiments.

It is evident that there will ultimately be required a well-equipped laboratory specially suited to the solving of those problems which are sure to develop, but since the equipment of such a laboratory as could be laid down at this time might well prove unsuited to the needs of the early future, it is believed that such provision should be the result of gradual development.

The investigations which the committee proposes in its program for the coming year can only be carried out to a satisfactory degree, with the limited facilities already existing, provided sufficient funds are made available. The estimates of the committee are based on such line of action, and on the assumption that a flying field can be placed at its disposal on Government land. If, however, such facilities be not practicable at this time, some progress may still be made by the utilization of the facilities of the Government aeronautic stations at Pensacola and San Diego.

The estimate of expenses for the fiscal year ending June 30, 1917, is as follows:

For carrying into effect the provisions of the act approved March third, nineteen hundred and fifteen, establishing a national advisory committee for aeronautics, there is hereby appropriated, out of any money in the Treasury not otherwise appropriated, for experimental work and investigations undertaken by the committee, including technical and clerical assistants and the necessary unskilled labor, equipment, supplies, office rent, and the necessary traveling expenses of the members and employees of the committee, personal services in the field, and in the District of Columbia: *Provided*, That an annual report to the Congress shall be submitted through the President, including an itemized statement of expenditures, $85,000.

The committee, therefore, submits its report, recommendations, and estimates to your favorable consideration.

Very respectfully,

George P. Scriven,
Brigadier General, Chief Signal Officer of the Army,
Chairman.

ANNUAL REPORT OF THE NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
STATE, WAR, AND NAVY BUILDING,
Washington, D. C., December 9, 1915.

To the Congress:

The members of the National Advisory Committee for Aeronautics were appointed by the President on April 2, 1915, in pursuance of the following provision in the naval appropriation act (Public, No. 271, 63d Cong.), approved March 3, 1915:

An Advisory Committee for Aeronautics is hereby established, and the President is authorized to appoint not to exceed twelve members, to consist of two members from the War Department, from the office in charge of military aeronautics; two members from the Navy Department, from the office in charge of naval aeronautics; a representative each of the Smithsonian Institution, of the United States Weather Bureau, and of the United States Bureau of Standards; together with not more than five additional persons who shall be acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences: *Provided*, That the members of the Advisory Committee for Aeronautics, as such, shall serve without compensation: *Provided further*, That it shall be the duty of the Advisory Committee for Aeronautics to supervise and direct the scientific study of the problems of flight, with a view to their practical solution, and to determine the problems which should be experimentally attacked, and to discuss their solution and their application to practical questions. In the event of a laboratory or laboratories, either in whole or in part, being placed under the direction of the committee, the committee may direct and conduct research and experiment in aeronautics in such laboratory or laboratories: *And provided further*, That rules and regulations for the conduct of the work of the committee shall be formulated by the committee and approved by the President.

That the sum of $5,000 a year, or so much thereof as may be necessary, for five years is hereby appropriated, out of any money in the Treasury not otherwise appropriated, to be immediately available, for experimental work and investigations undertaken by the committee, clerical expenses and supplies, and necessary expenses of members of the committee in going to, returning from, and while attending meetings of the committee: *Provided*, That an annual report to the Congress shall be submitted through the President, including an itemized statement of expenditures.

APPOINTMENT OF COMMITTEE.

Under the authority of the statute the President appointed the following members of the committee:

Prof. Joseph S. Ames,
Johns Hopkins University, Baltimore, Md.
Capt. Mark L. Bristol, United States Navy,
Director of Naval Aeronautics, Navy Department.
Prof. William F. Durand,
Leland Stanford Junior University, Stanford University, Cal.

Prof. John F. Hayford,
Northwestern University, Evanston, Ill.
Prof. Charles F. Marvin,
Chief, United States Weather Bureau.
Hon. Byron R. Newton,
Assistant Secretary of the Treasury, Treasury Department.
Prof. Michael I. Pupin,
Columbia University, New York, N. Y.
Lieut. Col. Samuel Reber, United States Army,
Officer in Charge Aviation Section, War Department.
Naval Constructor Holden C. Richardson, United States Navy,
Navy Department.
Brig. Gen. George P. Scriven, United States Army.
Chief Signal Officer, War Department.
Dr. S. W. Stratton,
Director, United States Bureau of Standards.
Dr. Charles D. Walcott,
Secretary, Smithsonian Institution.

RULES AND REGULATIONS.

The approved rules and regulations for the conduct of the work of the National Advisory Committee for Aeronautics, as approved by the President on June 14, 1915, are as follows:

RULES.

1. The committee may exercise all the functions authorized in the act establishing an advisory committee for aeronautics.
2. The committee, under regulations to be established and fees to be fixed, shall exercise its functions for the military and civil departments of the Government of the United States, and also for any individual, firm, association, or corporation within the United States: *Provided*, *however*, That such department, individual, firm, association, or corporation shall defray the actual cost involved.
3. No funds shall be expended for the development of inventions, or for experimenting with inventions for the benefit of individuals or corporations.

REGULATIONS FOR CONDUCT OF COMMITTEE.

Article I.

MEETINGS.

1. The annual meeting of the advisory committee shall be held in the city of Washington, in the District of Columbia, on the Thursday after the third Monday of October of each year. A semiannual meeting of the advisory committee shall be held on the Thursday after the third Monday in April of each year, at the same place.
2. Special meetings of the advisory committee may be called by the executive committee, by notice served personally upon or by mail or telegraph to the usual address of each member at least five days prior to the meeting.
3. Special meetings shall, moreover, be called in the same manner by the chairman, upon the written request of five members of the advisory committee.
4. If practicable, the object of a special meeting should be sent in writing to all members, and if possible a special meeting should be avoided by obtaining the views of members by mail or otherwise, both on the question requiring the meeting and on the question of calling a special meeting.
5. Immediately after each meeting of the advisory committee a draft of the minutes shall be sent to each member for approval.
6. There shall be monthly meetings of the executive committee.

ARTICLE II.

OFFICERS.

1. The officers of the advisory committee shall be a chairman and a secretary, who shall be elected by the committee by ballot, to serve for one year.

2. The chairman shall preside at all meetings of the committee and shall have the usual powers of a presiding officer.

3. The secretary shall issue notices of meetings of the committee, record its transactions, and conduct the correspondence relating to the committee and to the duties of his office.

ARTICLE III.

COMMITTEES.

1. There shall be an executive committee which shall consist of seven members, to be elected by the advisory committee by ballot from its membership, for one year. Any member elected to fill a vacancy shall serve for the remainder of his predecessor's term. The executive committee shall elect its chairman.

2. The executive committee in accordance with the general instructions of the advisory committee, shall control the administration of the affairs of the committee, and shall have general supervision of all arrangements for research, and other matters undertaken or promoted by the advisory committee; and shall keep a written record of all transactions and expenditures, and submit the same to the advisory committee at each stated meeting; and it shall also submit to the advisory committee, at the annual meeting, a report for transmission to the President.

3. The executive committee is authorized to collect aeronautical information, and such portion thereof as may be appropriate may be issued as bulletins or in other forms.

4. There may be subcommittees appointed by the executive committee, the chairmen of which shall be members of the advisory committee, and the other members of which may or may not be members of the advisory committee.

5. All officers and all members of committees hold office until their successors are elected or appointed.

ARTICLE IV.

FINANCES.

1. No expenditures shall be authorized or made except in pursuance of a previous appropriation by the advisory committee, or by authority granted by the advisory committee to the executive committee.

2. The fiscal year of the committee shall commence on the 1st day of July of each year.

3. The executive committee shall provide for an annual audit of the accounts of the advisory committee, and shall submit to the annual meeting of the advisory committee a full statement of the finances and work of the committee, and a detailed estimate of the proposed expenditures for the succeeding fiscal year.

4. The Paymaster General of the Navy shall be the disbursing officer for such funds as may be appropriated for the use of the advisory committee. The chairman of the advisory committee, or the chairman of the executive committee, if authorized by the advisory committee, shall approve all accounts for the disbursement of funds.

5. Contributions of funds or collections for any purpose for aeronautics may be made to the Smithsonian Institution, and disbursements therefrom shall be made by the said institution.

ARTICLE V.

AMENDMENTS.

1. Amendments to these rules and regulations may be made at any stated meeting by a two-thirds vote of the advisory committee, subject to approval by the President.

ORGANIZATION OF COMMITTEE.

Pursuant to a call of the Secretary of War, by direction of the President, the members of the Advisory Committee for Aeronautics met in the office of the Secretary of War on April 23, 1915. The first meeting was called to order by the Secretary of War, and a temporary

organization was effected. Brig. Gen. George P. Scriven, United States Army, was elected temporary chairman, and Naval Constructor Holden C. Richardson, United States Navy, temporary secretary.

In conformity with the designation in the call for the first meeting, issued by the Secretary of War, the word "National" was prefixed to the terms "Advisory Committee for Aeronautics."

Under the authority of the rules and regulations the organization was completed by the election of officers for one year as follows:

Brig. Gen. George P. Scriven, United States Army, chairman.
Naval Constructor Holden C. Richardson, United States Navy, secretary.

Officers and Members of Executive Committee.

OFFICERS.

Dr. Charles D. Walcott, chairman.
Naval Constructor H. C. Richardson, secretary.

MEMBERS.

Prof. Joseph S. Ames.
Capt. Mark L. Bristol, United States Navy.
Prof. Charles F. Marvin.
Prof. Michael I. Pupin.
Lieut. Col. S. Reber, United States Army.
Dr. S. W. Stratton.

WORK OF THE COMMITTEE.

The executive committee was directed to consider a program of investigation and procedure intended to carry into effect the purposes of the act creating the advisory committee, and to report the same with recommendations. The recommendations and the report of the executive committee were approved by the general committee at the annual meeting, and are incorporated in this report.

The authority of the advisory committee was given to the executive committee to institute special investigations that promised to be of service to aviation. The results are shown in the reports forwarded herewith as appendices. The limited time and the limited funds available both combined to prevent the accomplishment of additional work of importance, which might otherwise have been undertaken.

The executive committee instituted an investigation of facilities available in various colleges, technical and engineering institutions, and among manufacturers and various aeronautic societies, for the carrying on of aeronautic investigations. It was found that limited facilities were available for attacking various problems of aeronautic design, and that same could be made available to the committee, provided funds were available to carry out the necessary experiments, or to engage competent engineers on different phases of the work. A number of institutions have available mechanical laboratories and engineering courses capable of application to aeronautics, but only the Massachusetts Institute of Technology and the University of Michigan so far offer regular courses of instruction and experimentation. Worcester Polytechnic Institute has conducted experiments on full-sized propellers mounted on a whirling table turning on a pivot in the middle of a pond. The arms of the whirling table are provided at one end with a dynamometer for measuring the torque and thrust and revolutions of the propeller, and at the center a control stand for controlling the speed of the propeller. The speed

of the rotating arm is controlled by means of a drag in the water, attached to the opposite end of the rotating arm. While there are objections to this method of testing in a circular path in the open, the method is ingenious and the results obtained should be valuable, particularly for comparison. In general, however, it appears that the interest of colleges is more one of curiosity than that of considering the problem as a true engineering one, requiring development of engineering resources and, therefore, as not yet of sufficient importance to engage their serious attention. Manufacturers are principally interested in the development of types which will meet Government requirements or popular demand, but which will not involve too radical or sudden changes from their assumed standard types.

As a result of the investigations of the facilities available in this country, and of the problems requiring solution, it is found that many problems exist requiring careful and thorough investigation, which could be attacked with facilities which can be placed at the disposal of the committee, provided sufficient funds are made available. Considerable work has already been accomplished in aeronautics with which the general public is not acquainted. This covers lines of development and investigation which if published would save money and effort on the part of individual investigators and inventors who are now duplicating investigations already made by others. Some of these investigations have resulted in improvement; others have shown the futility of development on certain lines. Some of this information is already embodied in reports which are only accessible to a few interested parties who know of its existence. Much can be accomplished by making the results of such investigations accessible, either in a reference library or in the form of reports.

PROBLEMS.

Of the many problems now engaging general attention, the following are considered of immediate importance and will be considered by the committee as rapidly as funds can be secured for the purpose:

A. *Stability as determined by mathematical investigations.*—The reduction to practical form of the analytical methods of determining the stability of aeroplanes from design data, without necessarily requiring wind-tunnel tests or full-sized tests of same.

(*a*–1) This will require first a thorough investigation by competent mathematicians and physicists of the work so far accomplished by different authorities of prominence in this country and abroad. The publication of many valuable treatises which have already been prepared is not sufficient, as many of these treatises are presented in such highly technical manner that they are not in form to be comprehended by designers and manufacturers who are otherwise fitted for practical accomplishments in aeronautical work.

(*a*–2) Another phase of these investigations is the natural tendency on the part of designers and constructors to assume that mathematical theories are of use only to those who are mathematically inclined; and there is objection, frequently based on good ground, that in order to arrive at solutions of the complicated equations involved, mathematicians necessarily make certain assumptions which are not always based on actual conditions, and though the

conclusions drawn are logical, based on the assumptions made, there is reasonable doubt if the resulting conclusions apply to a complete machine. Until such distrust is overcome, true engineering progress in the design of air craft will be hampered and progress will depend, much as in the past, on "cut and try" methods. However, when the mathematician can explain by a correct application of mathematical analysis why certain things occur in practice, for which no satisfactory solution has been found, a start will be made toward the removal of the distrust of mathematical formulæ and real progress begin. As an instance of such application attention is invited to the report of Hunsaker and Wilson, of the Massachusetts Institute of Technology (Report No. 1), in which it is shown that although an aeroplane is designed so that statically it is stable to a satisfactory degree, it does not necessarily follow that the machine is dynamically stable; and in fact in the case investigated it was found that while within certain limits the machine was dynamically stable, the limits of dynamic stability were much smaller than supposed, and at low speeds dynamic instability existed to such a degree as to require correction in the design. Such instability has probably been the cause of a large number of accidents, and yet constructors and designers were at a loss to explain the cause until demonstrated by the test of a model of an actual machine in a wind tunnel.

B. *Air-speed meters.*—An important problem to aviation in general is the devising of accurate, reliable, and durable air-speed meters and other aeronautic instruments for the navigation and control of air craft.

(*b*–1) The most important of these problems is that of the prevention of "stalling" of aeroplanes. The committee considers "stalling" responsible for a very high percentage of aeroplane accidents. It is believed that at present the possibility of stalling exists in all machines, except a few which have been specially designed to have a high degree of inherent longitudinal stability; but it appears desirable and necessary to use machines of a normal type, because of certain considerations affecting the methods of using these machines in warfare and also because of certain restrictions involved in the performances of machines of the inherently stable type. The best means of preventing stalling is the development of a reliable air-speed meter, which by its indications will give warning of the approach to those conditions which produce stalling. A number of such meters already exist in different forms, but none so far developed or brought to the attention of the committee is considered to be satisfactory or reliable.

(*b*–2) The Bureau of Standards is now engaged in investigation of such meters, and attention is invited to the report of Prof. Herschel and Dr. Buckingham of the bureau on Pitot tubes. (Report No. 2.) In addition to the investigation by the Bureau of Standards referred to, a number of manufacturers and individuals are already engaged in the development of air-speed meters. The development of other forms of aeronautical instruments is in a more satisfactory condition and is progressing steadily.

C. *Wing sections.*—The evolution of more efficient wing sections of practical form, embodying suitable dimensions for an economical structure, with moderate travel of the center of pressure and still affording a large range of angle of attack combined with efficient action.

D. *Motors.*—The development of high powered aeronautic motors of the lightest possible construction consistent with reliable operation and the maximum economy of fuel and oil consumption.

(*d*–1) The committee is of the opinion that with proper encouragement, satisfactory types of aeroplane motors can be developed which will rival in efficiency and certainty of operation the automobile motors of to-day and the best aeronautic motors which have been developed abroad. This will require that manufacturers having capable organizations at their disposal shall become interested in aeronautic development and see a market for their products. In the meantime, both the War and Navy Departments are already engaged on this problem and may be expected to contribute valuable information in the near future. By employing some of the most competent engineers of this country on investigations of the many complicated details of design of gas engines, the committee should be able to make substantial progress on these lines.

(*d*–2) An efficient form of radiator is needed, which will provide satisfactory cooling for water cooled motors, without involving too much weight or resistance, and it is desirable that the principles of design should be carefully investigated with a view to the development of a type which will embody the different qualities required in such a manner as to have the least unfavorable effect on the aerodynamic efficiency of aircraft.

(*d*–3) An efficient form of muffler for internal combustion engines is necessary for military aircraft. An attempt by the committee to obtain a report on this subject has so far been unfruitful, though it is hoped that satisfactory progress can be made in the near future. The problem is not a simple one on account of the high power of the motors used.

E. *Propellers.*—The development of more efficient air propellers, which will hold their efficiency at high values over a large range of speed of advance. Also improvements in design of propellers relative to materials and details of construction, leading toward reduced weight and greater permanence of form, together with provision for ready repairs and moderate cost of construction.

(*e*–1) It is considered that this country has available a number of competent authorities on propellers for water craft, who are thoroughly equipped to place the design of aeronautic propellers on a satisfactory basis, and it is advisable that the committee should have at its disposal funds to engage such talent on the development of propeller design. A great deal of work has already been accomplished abroad and is available for use, and though high efficiency of design has been attained abroad, the progress on these lines in this country has been limited.

F. *Form of aeroplane.*—Improvements in the form of aeroplane leading toward natural inherent stability to such a degree as to relieve largely the attention of the pilot while still retaining sufficient flexibility and control to maintain any desired path, without seriously impairing the efficiency of the design.

G. *Radio-telegraphy.*—It is exceedingly desirable that the committee should investigate the question of apparatus to be used in sending messages from aeroplanes in order that there may be sure means of communication between the aeroplane and fixed base stations.

PHYSICAL PROBLEMS.

Beside the more general problems, the following problems of a physical rather than aeronautical nature are of particular interest:

A. *Noncorrosive materials.*—The availability of noncorrosive materials for construction details and fittings; such materials to have qualities comparable with those attainable in different grades of steel, both as to physical properties and as to reliability.

(*a*–1) Work on this line is already well in hand at the Bureau of Standards.

B. *Flat and cambered surfaces.*—A complete investigation of the effects of combinations of flat and cambered surfaces joined by hinges, as is usual in the construction of rudders.

(*b*–1) No extended work on these lines has yet been carried out, though facilities exist at the Washington Navy Yard and at the Massachusetts Institute of Technology.

C. *Terminal connections.*—The development of reliable terminal connections for truss wires, which will develop, if practicable, the full strength of the wire without involving too much bulk or weight, and without involving danger due to unusual care being required in attaching same; that is, the solution must be a practical and not a laboratory one.

(*c*–1) A valuable contribution to this question is submitted in the report volunteered by the John A. Roebling's Sons Co. (Report No. 3.)

D. *Characteristics of constructive materials.*—An accurate and authentic determination of the physical characteristics of all classes of woods, metals, and fabrics which enter into the present-day types of construction.

(*d*–1) Considerable information on these lines is undoubtedly available in the laboratory records of various technical institutions, but is not generally accessible. The Bureau of Standards is well equipped for this line of work.

E. *Generation of hydrogen.*—The generating of hydrogen economically at sea on a ship rolling in a seaway is a problem to be solved.

(*e*–1) There are many systems of generating hydrogen on land, but many of these would be defective if installed aboard ship. Any installation for this purpose aboard ship should combine capacity, compactness and economy, and certainty of operation to the highest degree.

F. *Standardization of nomenclature.*—The standardization of aeronautical nomenclature is most desirable for the whole country.

(*f*–1) This question has already been attacked by the Army and Navy, and the reports of these branches of the service should form a good basis for the work of the committee.

G. *Standardization of specifications.*—Standardization of specifications for aeroplane materials for use of the Government and people of this country.

(*g*–1) A proposition on these lines from a prominent manufacturer has already been received, and the committee has taken steps toward the development of such specifications.

H. *Bibliography of aviation.*—Revision and continuation of the bibliography of aviation.

I. *Collection, revision, and issuance of reports* and bulletins covering the state of the art of aeronautics, the primary purpose being to avoid

as far as possible unnecessary duplication of work which has already been well done.

J. *Limitation of size.*—Determination of the present upper limits with regard to size and carrying capacity, with special reference to the means by which those limits may be extended, it being very important to know approximately the present limitations in size and carrying capacity and to what elements these limitations apply, and why.

K. *Causes of accidents.*—Securing and carefully compiling of reports of causes of accidents in aeronautics.

(k–1) While conditions have changed decidedly from the early days of aeronautics in this country, there is still evidence of carelessness in the design and operation of aeroplanes. It would appear as coming within the province of this committee that legislation should be enacted toward obtaining control of this feature at an early date. However, any such legislation should be most carefully considered and the views of those interested should be obtained. This is particularly necessary, as already a number of attempts have been made toward legislation in different States, with the result that in one State, at least, experimental work is practically prohibited, not because inventors and constructors can not comply with the law, but because the operation of the law requires facilities which do not exist in the State in which the laws have been passed. With a view toward determining the requirements of such legislation, it is proposed that a beginning be made by requesting that all accidents be reported to the advisory committee on forms to be published by the committee, embodying a set of categorical questions, the answers to which may lead to a determination of the principal causes of accidents. In cases where such accidents result in the maiming or killing of spectators or flyers, such questions should be answered by the investigating authorities. The word "request" is used in view of the possible conflicts of State and Federal authority and jurisdiction; and whereas it is very probable that both State and Federal authorities would be willing and glad to cooperate in this work in response to a request, it is not clear that such cooperation would follow legislation, unless carefully worked out.

STANDARDS OF WORK.

While the functions of the committee are not considered directly to be concerned with the question of preparations for defense, in the opinion of the committee it is of greatest importance that the manufacturers of aircraft and the War and Navy Departments, at present the principal consumers, should come to a definite agreement as to the standards of work necessary to facilitate production and repairs. Of the most importance in this line is the preparation of standard specifications for materials and tests. In this manner the producers and consumers will have a clear understanding on which to base contracts, and under the stress of war conditions the multiplication of aircraft would be greatly facilitated.

IMPORTANCE OF WORK TO ARMY AND NAVY.

The importance of aircraft to the War and Navy Departments, in view of the utilization of such craft in the present war in Europe, is so evident that no further comment is offered. It is, however, strongly recommended that every consideration should be given toward the provision of adequate facilities for initiating and conducting the important experimental work necessary for the efficient development of both branches of the service on aeronautical lines.

QUARTERS FOR COMMITTEE.

By courtesy of the Secretary of War, the first meetings of the advisory committee and the executive committee were held in the reception room in the office of the Secretary of War, and the annual meeting was also held in that room. In accordance with the instructions of the advisory committee, the executive committee attempted to obtain quarters in the State, War, and Navy Department Building, but found that each of these departments was so crowded for space that none was available. However, through the courtesy of the Secretary of War, the meetings of the executive committee have been held in the private office of the officer in charge of the Aviation Section, War Department, and the office work of the committee has been temporarily conducted and the files have been kept in a portion of a room adjoining the same office. While such improvised quarters for the committee served their purpose, such temporary quarters are not satisfactory or suited to the needs of the committee. Suitable quarters can be obtained at moderate cost in one of the several office buildings centrally located in the city of Washington. It is for this reason the committee recommends that provision for suitable quarters be made in the next appropriation act.

EXISTING FACILITIES FOR AERONAUTIC INVESTIGATION IN GOVERNMENT DEPARTMENTS.

For the conduct of the work outlined, limited facilities already exist in different Government departments about as described in general terms in the following. These facilities can be augmented by the facilities described as existing in the different technical institutions, etc., previously referred to:

A. The Bureau of Standards is well equipped for carrying on all investigations involving the determination of the physical factors entering into aeronautic design, and is prepared to take up such matters as are of sufficient general interest to warrant same.

B. The Navy Department is equipped with a model basin and wind tunnel at the Washington Navy Yard, with adequate shop facilities for carrying on the work in a limited way, and is also constructing at the Washington Navy Yard a plant for the testing of aeronautic motors and devices involved in their operation, which will be in commission at an early date. Also, under the Navy Department steady progress is being made in attacking practical problems involved in the development of the Navy aeronautic service at its station at Pensacola, and theoretical and practical designs are in hand in the Bureaus of Construction and Repair and Steam Engineering.

C. The War Department has limited facilities at the flying school at San Diego, for investigations of interest to that branch of the service, and is able to carry out in a limited way experiments of interest to the service on full-sized machines, for which work it has the assistance of technical experts.

D. The Weather Bureau is well equipped for the determination of the problems of the atmosphere in relation to aeronautics, and Prof. Marvin, a member of the advisory committee, is the chairman of a subcommittee engaged on this problem. The work, however, will necessarily be limited until the necessary funds for more extensive work become available. There is already available in the records of the bureau much information of value which requires compilation in a form suited to aeronautic requirements, and this work is the subject of a preliminary report included in the annual report of the committee.

E. The Smithsonian Institution has been engaged for a number of years on the compilation of the bibliography of aeronautics, and is prepared to continue this work for at least two years more with the funds at its disposal. The institution has also contributed funds toward the development of the work of the subcommittee of the Weather Bureau in its investigation of the problem of the atmosphere in relation to aeronautics.

Itemized statement of expenditures under appropriation "Advisory Committee for Aeronautics, 1915."

No.	Payee.		Amount.
1150	J. F. Victory		$26.67
1155	Underwood Typewriter Co		67.50
1156	Union Envelope Co		4.23
1157	Andrews Paper Co		.79
1158	Municipal Supply Co		7.00
1159	Roberts Numbering Machine Co		2.40
1160	Globe-Wernicke Co		1.75
1161	E. J. Murphy Co		2.05
1162	Shaw-Walker Co		10.32
1163	.....do		9.16
1229	Transfer (supplies drawn from navy yard)		51.26
1420	A. B. Dick Co		75.00
1435	Postal Telegraph Cable Co		3.89
1436	Western Union Telegraph Co		20.39
1550	Joseph N. Snellenburg		67.00
1615	Prof. Michael I. Pupin		21.80
1617	.....do		21.80
1640	Massachusetts Institute of Technology		800.00
1641	Columbia University		1,500.00
7669	Prof. John F. Hayford		26.25
7670	Prof. William F. Durand		213.10
7775	Prof. Joseph S. Ames		3.70
			2,936.06
	OBLIGATED.		
	Cornell University	$1,000.00	
	United States Rubber Co	1.00	
	Goodline Manufacturing Co	1.88	
			1,002.88
	Total expended and obligated		3,938.94

A statement showing the expenditures of the committee is submitted herewith.

Summary of expenditures under appropriation "Advisory Committee for Aeronautics, 1915."

Clerical services	$26.67
Office furniture	67.00
Stationery and equipment	233.34
Members' traveling expenses	286.65
Telegrams	24.28
Technical reports from Massachusetts Institute of Technology, United States Rubber Co., Columbia and Cornell Universities	3,301.00
Total expended and obligated	3,938.94
Unobligated balance turned into Treasury	1,061.06
Amount of appropriation	5,000.00

CONCLUSIONS.

From the above, it will be apparent that utilizing all facilities at present available, the progress that can be made will be fragmentary and at best lack that coordination which is necessary to accomplish in a direct, continuous, and efficient manner, and as rapidly as practicable, the important work now in sight. If the committee is to be prepared to keep pace with the increasing needs of the very rapid development already under way, stimulated by the unusual conditions existing in Europe, the facilities and technical assistance recommended are essential. While the needs at present are principally those which have an important bearing on military preparedness, the committee is of the opinion that aeronautics has made such rapid strides that when the war is over there will be found available classes of aircraft and a trained personnel for their operation, which will rapidly force aeronautics into commercial fields, involving developments of which to-day we barely dream.

Respectfully submitted.

George P. Scriven,
Brigadier General, Chief Signal Officer of the Army,
Chairman.

REPORTS

SUBMITTED TO

THE NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

IN SEVEN PARTS.

REPORT No. 1.

IN TWO PARTS.

REPORT ON BEHAVIOR OF AEROPLANES IN GUSTS.

BY THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

Part I.—EXPERIMENTAL ANALYSIS OF INHERENT LONGITUDINAL STABILITY FOR A TYPICAL BIPLANE.

By J. C. HUNSAKER.

Part II.—THEORY OF AN AEROPLANE ENCOUNTERING GUSTS.

By E. B. WILSON.

LIST OF ILLUSTRATIONS.

REPORT No. 1.

PART 1.

EXPERIMENTAL ANALYSIS OF INHERENT LONGITUDINAL STABILITY FOR A TYPICAL BIPLANE.

By Jerome C. Hunsaker.

Article 1.

INTRODUCTION.

A model of span 18 inches, representing a typical military tractor biplane, was tested in the wind tunnel of the Massachusetts Institute of Technology. The lift, drift, and pitching moment were measured for a series of angles of incidence corresponding to the maximum possible changes of flight attitude. Only the discussion of symmetrical or longitudinal changes is given here. A report on the lateral stability of the same model is reserved for a later date. From the observed rate of variation of the forces and pitching moment, it was possible to calculate the "derivatives" needed in the complete theory of longitudinal stability in still air. The damping of the pitching oscillation was also determined experimentally.

The method followed is that of L. Bairstow in his extension of Bryan's theory. Notation also follows Bairstow. The value of Routh's discriminant, which Bryan has shown to be a measure of dynamical longitudinal stability, has been calculated for six speeds, ranging from the maximum to the minimum possible speeds for the aeroplane type selected. The principal point of interest brought out in this connection is that stability falls off rapidly as speed decreases or angle of attack increases, and that while this aeroplane appears to be very stable at high speeds, it is frankly unstable at speeds below 47 miles per hour.

This instability at low speeds takes the form of an oscillation in pitch combined with changing in forward speed and a rising and sinking of the whole aeroplane, which, therefore, follows an undulatory flight path. The period of the undulation is about 12 seconds, and the amplitude doubles itself in less than 20 seconds. Obviously, the pilot can not safely abandon his controls at slow speed.

The importance of this demonstrated instability at low speeds should be appreciated in view of recent accidents with military aeroplanes when operated at slow speeds.

The entire investigation of inherent longitudinal stability was preliminary to the discussion of the effect of wind gusts. Naturally, it was first necessary to find a stable aeroplane and to obtain some idea

of the "range" of stability. It now appears that a typical aeroplane is inherently stable in the sense defined at high speeds only. The effect of gusts on the uncontrolled aeroplane will, therefore, be investigated only for the high-speed condition. At low speeds the aeroplane can not be left to itself in still air. Consequently, a discussion of its certain destruction if abandoned in gusty air appears unprofitable.

Article 2.

MODEL AND PROTOTYPE.

The type of aeroplane selected is a high-speed military biplane tractor known as *Curtiss JN2*. Shop plans of this aeroplane were kindly furnished by the Curtiss Aeroplane Co., Buffalo, N. Y., to whom acknowledgment must be made for much valuable assistance, including the experimental determination of moments of inertia, etc., by Dr. A. F. Zahm of that company.

The principal dimensions of the aeroplane were assumed as follows:

Weight full load	pounds..	1,800
Brake horsepower	horsepower..	110
Maximum speed for calculations	miles per hour..	79
Minimum speed for calculations	do....	43.7
Total wing area (including ailerons)	square feet..	384.0
Area fixed tail	do....	23.0
Area horizontal rudder	do....	19.0
Area vertical rudder	do....	7.8
Span of wings	feet..	36.0
Chord of wings	do....	5.3
Gap between wings	do....	5.3
Length of body	do....	26.0

The model was made geometrically similar to its prototype and one twenty-fourth scale. The general features are shown in the drawings of the model. (Figs. 1 *a*, *b*, *c*.) The model was an exact copy of the aeroplane except for the propeller and wing wiring, which features were omitted. Also wing struts were made round instead of "stream-line" in section. Since it is well known that the resistance of a series of similar aeroplanes varies somewhat less rapidly than the square of the speed and square of a linear dimension, due to skin friction, it is believed that the prediction of the resistance of the full size aeroplane from the observed model resistance will still be a fair estimate in spite of omissions on the model.

For simplicity, the model was made with the trailing ailerons or wing flaps integral with the wings. This somewhat increases the effective supporting area. Also the fixed tail and elevator were made in one, corresponding to the elevator held fast in its neutral position. These points are made clear on the drawings of the model.

Article 3.

GENERAL WIND TUNNEL PROCEDURE.

The model was tested in the 4-foot wind tunnel at a velocity of 30 miles per hour. The wind tunnel and aerodynamical balance are duplicates of the installation of the National Physical Laboratory, Teddington, England, and reference should be made to the Technical

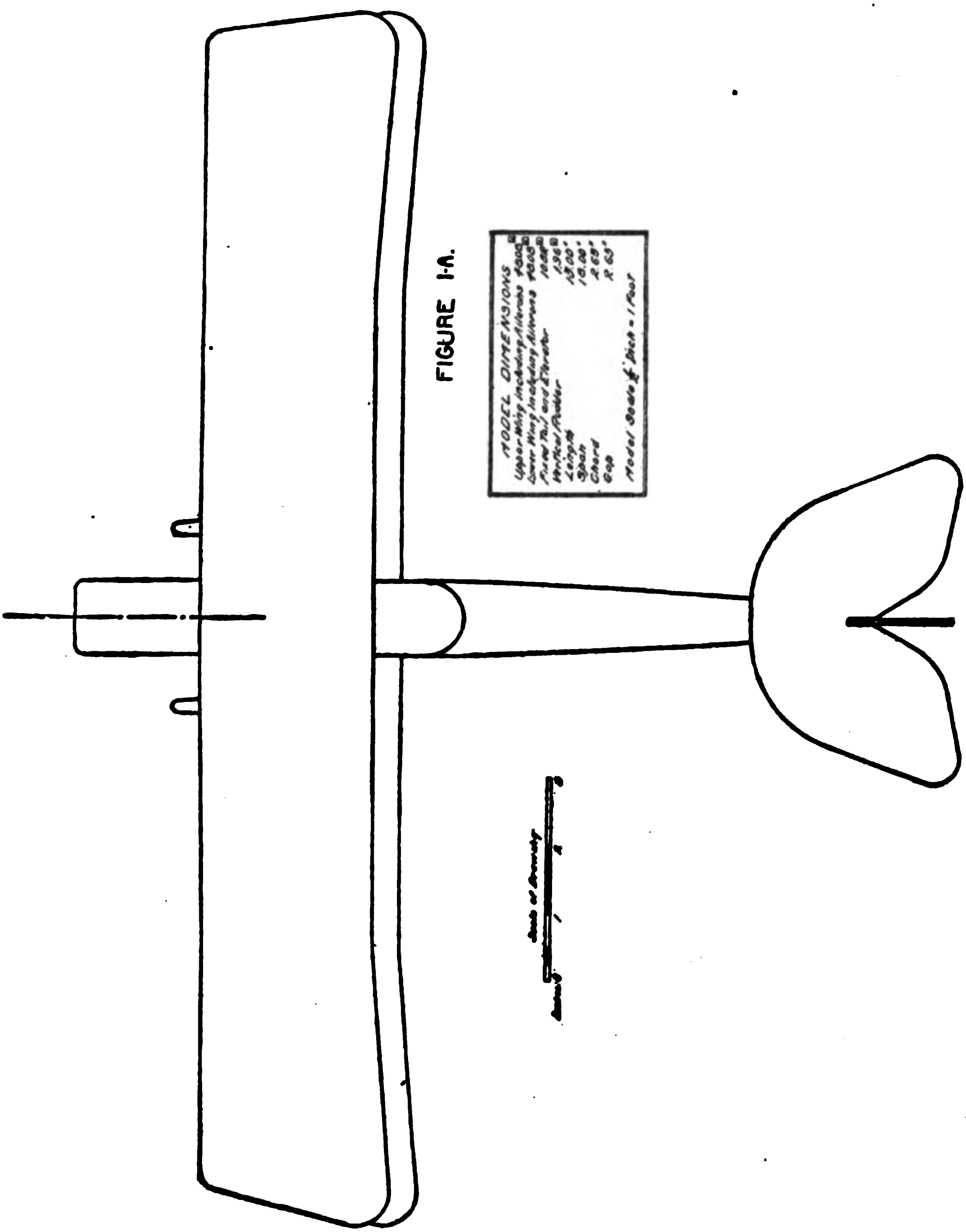
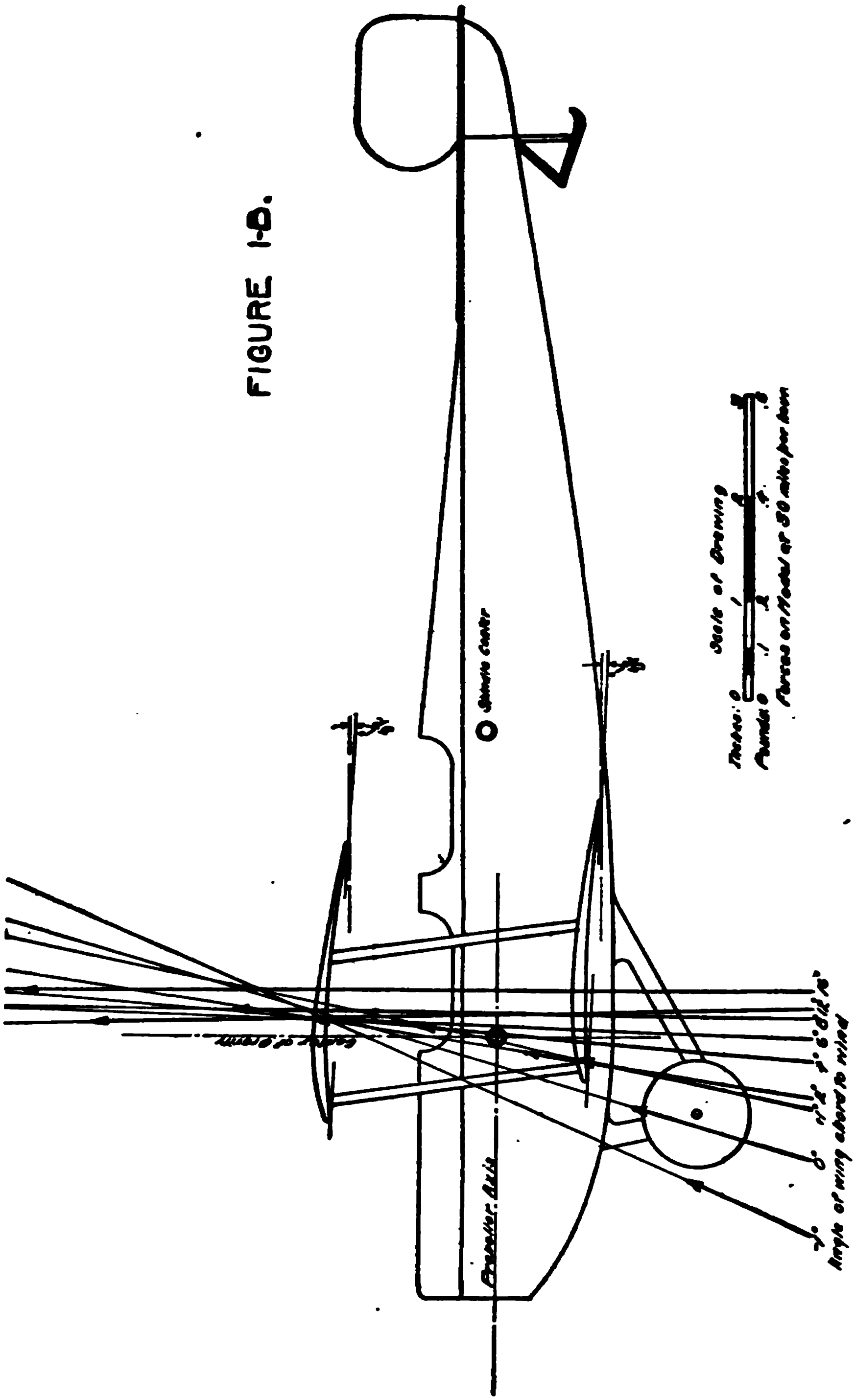

MODEL DIMENSIONS
Upper Wing including Ailerons
Lower Wing including Ailerons
Fixed Tail and Elevator
Vertical Rudder
Length
Span
Chord
Gap
Model Scale ¼ Inch = 1 Foot

FIGURE 1-A.

FIGURE 1-D.



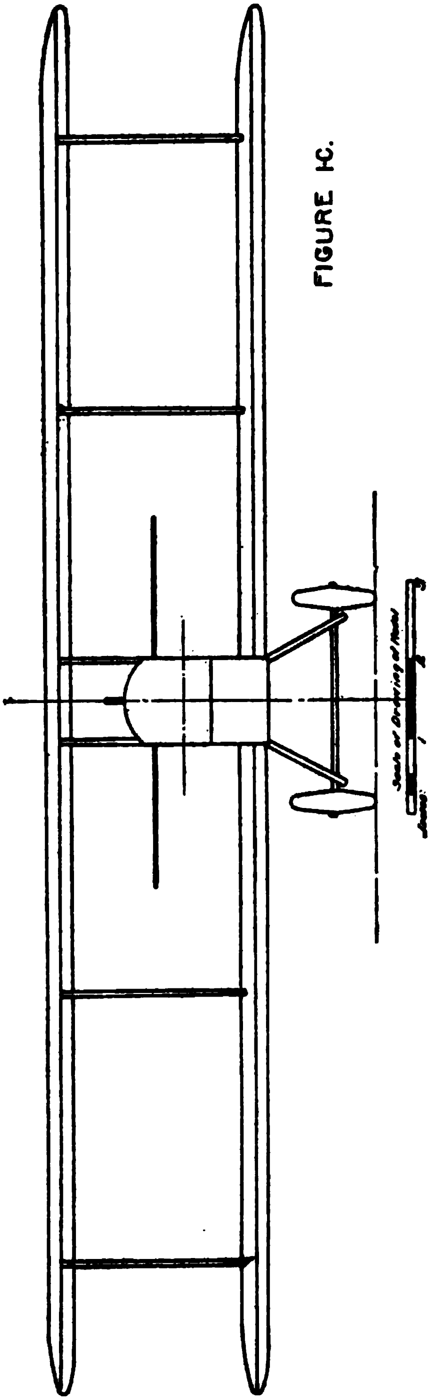


FIGURE 1C.

Report of the Advisory Committee for Aeronautics, London, 1912–13, for detail description and methods of operation.

In general, it may be stated that the wind tunnel provides a wind constant in velocity within 1 per cent, which velocity is further constant across the working cross section of the tunnel within 1¼ per cent. Velocity is measured by a suction plate calibrated against a standard Pitot tube with a precision of one-half per cent. The model is mounted on the balance in various attitudes of pitch or yaw, and in such positions are measured the three forces and three couples produced by the wind along and about three mutually perpendicular axes in space. From a knowledge of the variation of these forces and couples with change of attitude, the so-called "resistance derivatives" of Bryan's[1] theory of dynamical stability may be computed.

The theory of stability also requires the determination of the damping of oscillations about the center of gravity of the aeroplane. A special oscillating apparatus was built for these tests which will be described below. By oscillating the model in the wind and observing the decrement of amplitude with time, it was possible to estimate the "rotary derivatives."

Article 4.

LONGITUDINAL TESTS.

The model was mounted on the balance with its wings in a vertical plane by means of a vertical rod driven into the body at the point shown on figure 1*b*. By swinging the model about the vertical axis passing through the spindle, the angle of wind to the wing chord was varied from +20° to −8°. At each attitude the force across the wind or "Lift," force down wind or "Drift," and the pitching moment about the spindle were measured. The signs were taken so that an actual lift, actual head resistance, and a stalling moment are positive. The wind velocity was 30 miles per hour of standard dry air at 15° C. and 776 mm. Hg. The experimental points are shown on figure 2, where forces are in pounds and moments in inch-pounds. The precision of measurement is within 1 per cent.

For a given attitude, the resultant force on the model in pounds at 30 miles per hour is $R=\sqrt{L^2+D^2}$. This resultant makes an angle with the wind direction given by $\alpha=\tan^{-1}\frac{L}{D}$. The force R is observed to have a pitching moment M about the spindle axis. It may then be assumed to be situated so that the perpendicular from this axis to R is given by $x=\frac{M}{R}$. The vector R is thus determined in magnitude, direction, and line of application. The resultant force vectors R are shown on figure 1*b* to a scale 1 inch equals 0.2 pound. The vector R is purely an algebraic substitution for the complicated system of forces and couples acting on the aeroplane. The vectors are drawn relative to the aeroplane.

The center of gravity was assumed to lie as shown near the intersection of the propeller axis with the resultant force vector for 4°. At this attitude, then, the pitching moment should be nearly zero.

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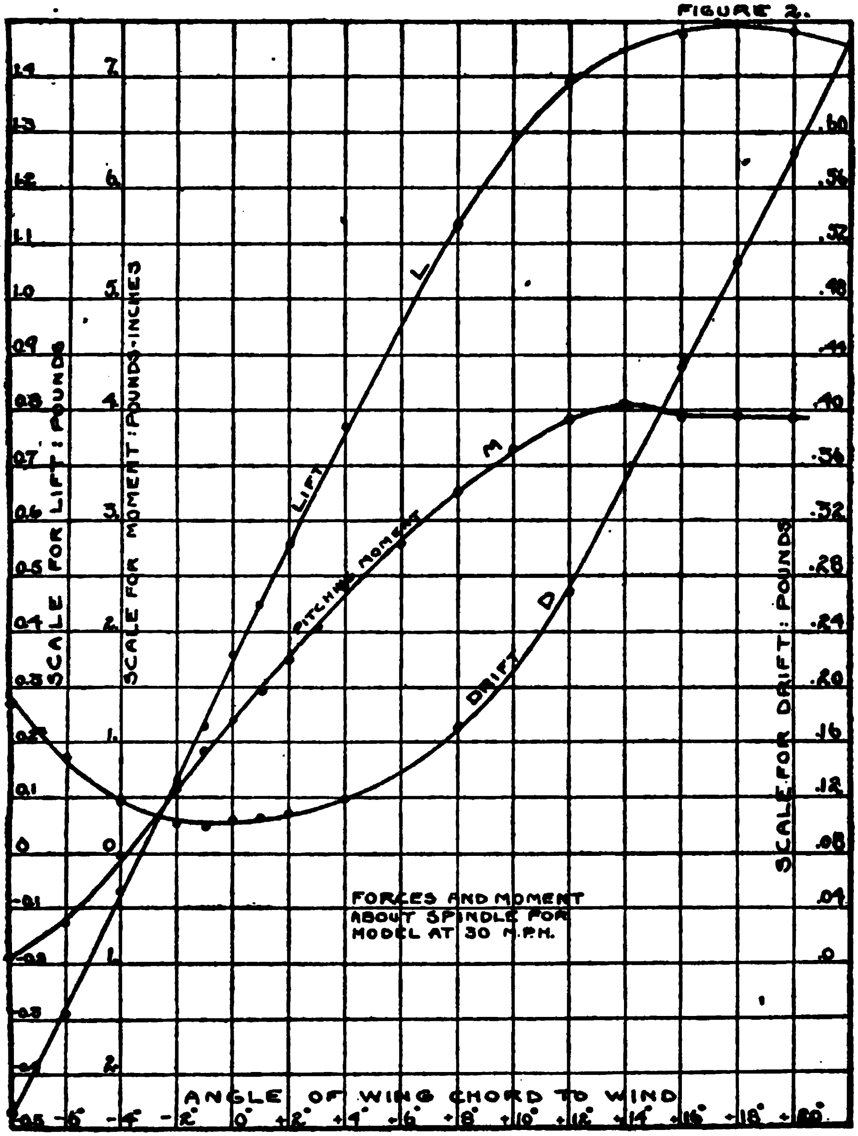
[1] G. H. Bryan, Stability in Aviation.

The c. g. location determined for the actual aeroplane after extensive trial flights is almost identical.

It is seen that for angles smaller than 4°, R passes forward of the

FIGURE 2.



c. g. and for angles greater than 4°, it passes to the rear. The aeroplane is longitudinally stable in a static sense. It will be shown below that it is not always dynamically stable.

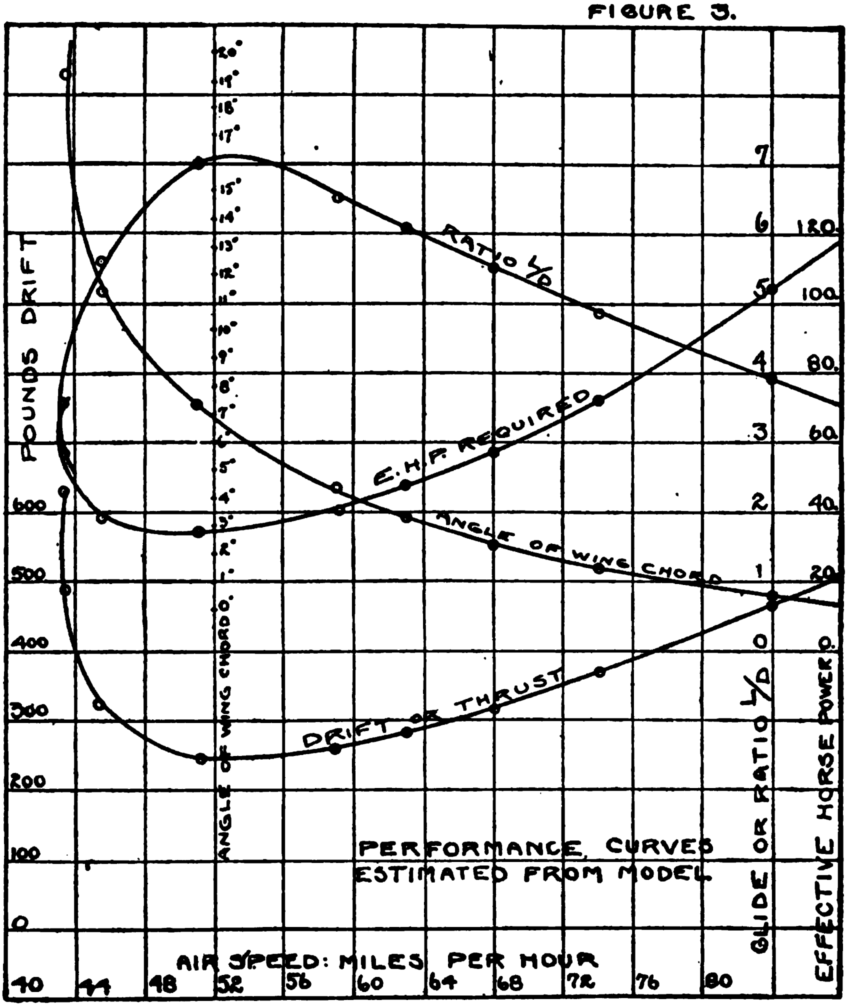
Article 5.

PERFORMANCE CURVES.

The lift and head resistance or "drift" of the full scale aeroplane were assumed to be approximately given by the relation:

$$\frac{\text{Force on model}}{\text{Force on aeroplane}}=\left(\frac{30}{24\ V}\right)^2$$

FIGURE 3.



when V is the flying speed of the aeroplane in miles per hour. The above relation holds, of course, only for the same attitude of model and aeroplane. The weight of the aeroplane, 1,800 pounds, must equal the lift in flight. Hence:

$$V=\frac{30}{24}\sqrt{\frac{1800}{\text{Lift on model.}}}$$

A series of speeds V was computed for a series of attitudes of the aeroplane, and the aeroplane drift at each attitude was then computed from:

$$D \text{ full size} = D \text{ model } \times \overline{24}^{2} \times \left(\frac{V}{30}\right)^{2}$$

In figure 3 are given curves of drift, effective horsepower required, angle of wing chord to wind and ratio weight to drift plotted on V as abscissae. For our calculations a maximum speed of 79 miles and a minimum of 43.7 miles were selected corresponding to angles of wing chord to wind of 1° and 15.5°, respectively.

The curve of E.H.P. on figure 3, indicates that 87 propeller horsepower is necessary for a speed of 79 miles. If the propeller has an efficiency of 80 per cent, the motor must develop at least 110 brake horsepower. The original designs contemplated as maximum speed of about 80 miles per hour for a 120 brake horsepower motor, which appears very reasonable. As actually built this type was given a rated 90 horsepower motor. Assuming 70 E.H.P. delivered to the propeller a speed of 73 miles per hour is indicated by our curves. It is reported that the speed of this aeroplane was actually 73 miles per hour.

Article 6.

CHOICE OF AXES—NOTATION—UNITS.

Axes for reference are assumed fixed in the aeroplane and moving with it in space. The origin is at the center of gravity. For steady horizontal flight at a given attitude the axis of Z is vertical, the axis of X Horizontal and directed to the rear in the plane of symmetry, and the axis of Y is horizontal and directed toward the left-wing tip. Forces along these axes are denoted by X, Y, Z and are expressed in pounds per unit mass. Moments are L, M, N and are given in pounds-feet per unit mass.[1]

Angles of roll, pitch and yaw from the normal flying attitude are denoted by φ, θ and ψ. Angular velocities of roll, pitch and yaw are p, q, r in radius per second. The signs of moments, angles and angular velocity are positive considered in the directions XY, YZ or ZX.

Moments of inertia referred to axes X, Y, Z are denoted by mK^2_A, mK^2_B, mK^2_C where m is the mass of the aeroplane and K_A, K_B, K_C corresponding radii of gyration.

Article 7.

EQUILIBRIUM CONDITIONS.

In normal horizontal flight in still air a state of equilibrium is assumed such that the power available maintains the aeroplane at such a speed that the weight is just sustained. Since the lift of an aeroplane wing is also a function of its attitude or angle of attack, it is further assumed that the attitude is proper for the speed. In

[1] Unit mass is the slug equal to 32.17 pounds weight.

normal horizontal flight the axis of X is parallel to the apparent wind direction and is hence horizontal. Let θ be the angle of pitch of the aeroplane away from its normal attitude. Then normally θ is zero. Likewise if the aeroplane is in equilibrium in its flight, the angular velocity of pitch is zero and also the pitching moment, M_o.

At high speed, for example 79 miles, the axis of X is horizontal and makes an angle of 1° with the wing chord. At low speed, new axes are chosen such that the axis of X is still horizontal but makes an angle of 15.5° with the wing chord. The axes are fixed by the equilibrium conditions for flight and differ for each normal flying attitude. Oscillations about the normal flight path when the motion is disturbed are referred to the above defined axes which are assumed fixed in the aeroplane and moving with it in space.

The pitching moment curve observed for the model shows zero moment for an angle of wing chord of 4.5° and a diving moment at larger angles. For slow flight, it is assumed that the pilot by proper setting of his horizontal rudder impresses an equal stalling moment on the machine so that the net pitching moment is zero. The effect is to move the pitching moment curve parallel to itself by the algebraic addition of a stalling moment so that its ordinate has zero value for the desired flight attitude.

Article 8.

TRANSFORMATION OF AXES.

It is convenient to measure in the wind tunnel the lift and drift about axes always vertical and horizontal in space. For the oscillations of the aeroplane it is convenient to consider the forces referred to axes fixed in the aeroplane as described above. The transformation is effected in the usual way by means of the formulæ:

$$m\ Z' = L \cos \Theta + D \sin \Theta,$$
$$m\ X' = D \cos \Theta - L \sin \Theta,$$

where Θ is the angle of pitch of the aeroplane away from its normal attitude, considered positive for stalling angles. Here L and D are lift and drift on the model in pounds, and $m\ X'$ and $m\ Z'$ corresponding forces in pounds along the axes X and Z. The model forces Z', X' are converted to Z, X, full size, by multiplying by the square of the speed and linear dimension ratios. The following tables carry out the required transformation.

The pitching moment M is independent of the longitudinal shift of axes and varies only as the square of the speed. Curves of X, Z and M for the different flight attitudes are plotted on figures 4, 5, 6, 7, 8, and 9. The transformation of the moment about the spindle to the corresponding moment about the c. g. of the full-size aeroplane is given below.

$i=1°$, $V=79$ miles, $m=55.9$ slugs.

i	θ	L	D	Z	X
−4	−5	−0.08	+0.115	−6.4	+7.7
−2	−3	+.14	.104	+10.8	7.8
0	−1	.35	.102	24.9	7.76
+1	0	.45	.104	32.9	7.4
+2	+1	.56	.108	40.0	7.1
+4	+3	.765	.118	54.9	5.6
+8	+7	1.13	.165	81.0	1.9
+12	+11	1.39	.270	100.0	−.7
+16	+15	1.48	.428	109.0	−2.05
+20	+19	1.48	.581	112.5	−4.7

$i=7°$, $V=51.8$ miles.

0	−7	+0.35	+0.102	+10.3	+4.42
1	−6	.45	.104	13.4	4.64
2	−5	.56	.108	16.9	4.79
4	−3	.765	.118	23.3	4.85
7	0	1.05	.150	32.2	4.60
12	+5	1.39	.270	48.0	4.54
16	9	1.48	.428	47.0	5.90
20	13	1.48	.581	48.2	7.12

$i=10°$, $V=47$ miles.

6	−4	+0.96	+0.136	+24.0	+5.14
8	−2	1.13	.165	28.4	5.18
10	0	1.28	.21	32.4	5.21
12	+2	1.39	.27	35.4	5.56
14	+4	1.45	.348	37.2	6.24

$i=12°$, $V=45.2$ miles.

8	−4	1.13	0.165	26.1	5.68
10	−2	1.28	.21	29.6	5.83
12	0	1.39	.27	32.4	6.29
14	+2	1.45	.348	34.0	6.92
16	+4	1.48	.428	35.2	7.56

$i=14°$, $V=44.2$ miles.

10	−4	1.28	0.21	28.3	6.67
12	−2	1.39	.27	30.8	6.87
14	0	1.45	.348	32.4	7.22
16	+2	1.48	.428	33.3	7.43
18	+4	1.50	.508	34.2	7.62

$i=15.5^\circ$, $V=43.7$ miles.

i	Θ	L	D	Z	X
9.5	−6	1.24	0.196	26.4	7.1
13.5	−2	1.40	.330	30.6	8.25
15.5	0	1.48	.408	32.2	8.9
17.5	+2	1.49	.482	33.0	9.4
19.5	+4	1.49	.561	33.4	10.0

CONVERSION OF PITCHING MOMENTS.

mM_s=moment about spindle in inch pounds on model.
$mM)_{cg}$=moment about c. g. in inch pounds on model.
b=3.04 inches, c. g. forward of spindle.
a=0.10 inches, c. g. above spindle.
Axis of X 3.5° to wing chord.
M=pitching moment about c. g. full size, full speed, in pounds feet per unit mass.
$mM_{cg}=mM_s-mZ'b-mX'a$.
i=angle of wing chord to wind, degrees.
Θ=angle of axis of X to wind, degrees.

i	θ	L	D	mZ'	mX'	mM_s	mM_{cg}	1° M	7° M	10° M	12° M	14° M	15°.5 M
−4½	−8	+0.130	+0.123	−0.146	+0.104	−0.022	+0.21	+20.9	+12.9	......	......	9.36	9.17
−2½	−6	+.080	.105	+.069	.112	+.400	+.18	+25.7	+11.0	......	......	8.0	7.85
−½	−4	+.300	.102	.293	.121	+1.05	+.15	+21.4	+9.2	......	......	6.67	6.54
+1½	−2	.510	.105	.506	.123	1.65	+.10	+14.3	+6.1	......	......	4.46	4.37
2½	−1	.615	.110	.613	.122	1.93	+.08	+11.4	+4.9	......	......	3.56	3.49
3½	0	.715	.115	.715	.115	2.21	+.03	+4.28	+1.8	......	......	+1.35	+1.32
4½	+1	.810	.122	.812	.107	2.48	00	0	0	0	0	0	0
5½	+2	.910	.130	.915	.098	2.71	−.08	−11.4	−4.9	−4.0	−3.72	−3.56	−3.49
7½	+4	1.09	.157	1.10	.081	3.17	−.18	−25.7	−11.1	−9.07	−8.40	−8.02	−7.86
11½	+8	1.37	.252	1.40	.058	3.81	−.40	−57.0	−24.5	−20.2	−18.7	−17.9	−17.5
15½	+12	1.48	.408	1.51	.184	4.00	−.60	−85.5	−36.8	−30.3	−28.0	−26.8	−26.2
19½	+16	1.49	.561	1.54	.331	3.95	−.76	−108.0	−46.6	......	......	−33.9	−33.2

ARTICLE 9.

RESISTANCE DERIVATIVES, LONGITUDINAL.

Notation follows Bairstow,[1] to whose paper reference should be made for the detailed discussion of "derivatives." In the theory of small oscillations, the aerodynamic forces X_0, Z_0, and pitching moment, M_0, are eliminated by the conditions of equilibrium. In disturbed motion, disturbances in normal flying speed and attitude cause changes in the quantities, X, Z, and M.

Let U be the normal flying speed and u, w and q small changes in horizontal and vertical velocity components and angular velocity of pitch. If the disturbance be small, u, w and q are small with respect to U. For example, the function

$$X=f(U+u, w, q)$$

may be expanded into the approximate form

$$X=X_0+uX_u+wX_w+q\,W_q,$$

a linear function of the small quantities u, w, q. The coefficients X_u, X_w, X_q are the so-called resistance derivatives of the theory of

[1] Technical Report of the Advisory Committee for Aeronautics, London, 1912-13.

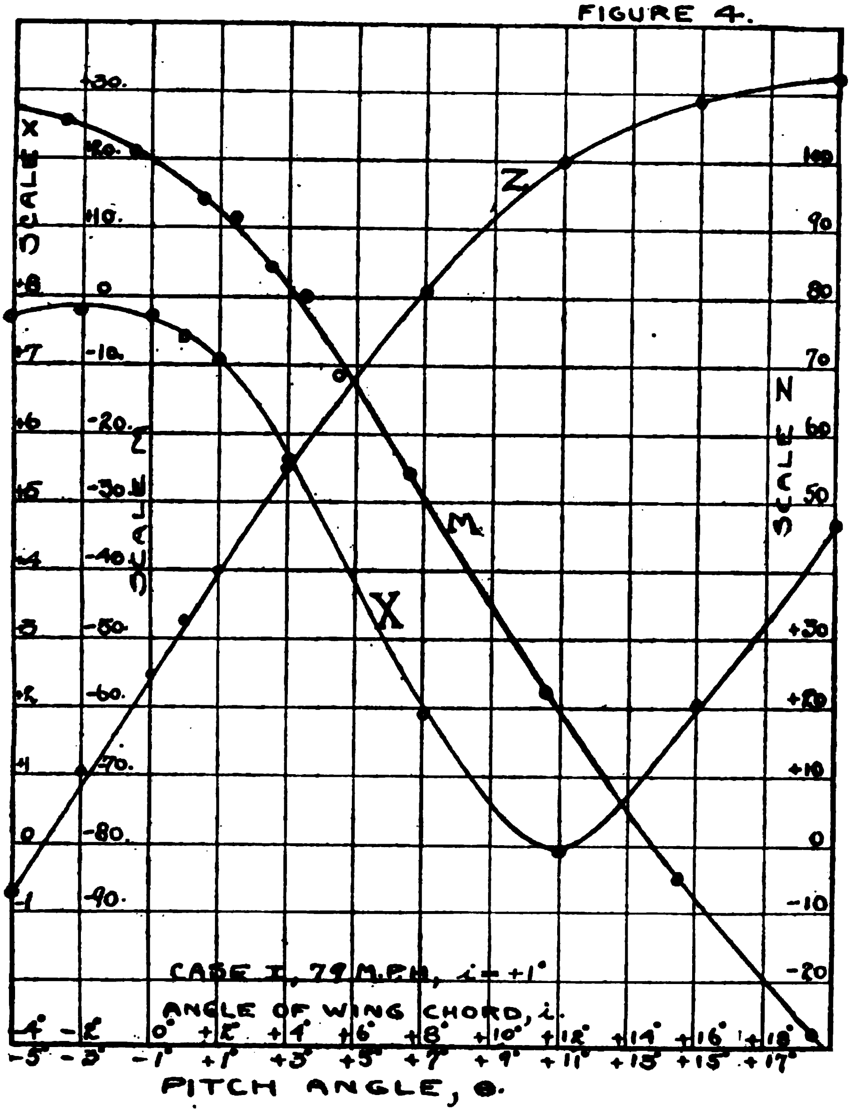
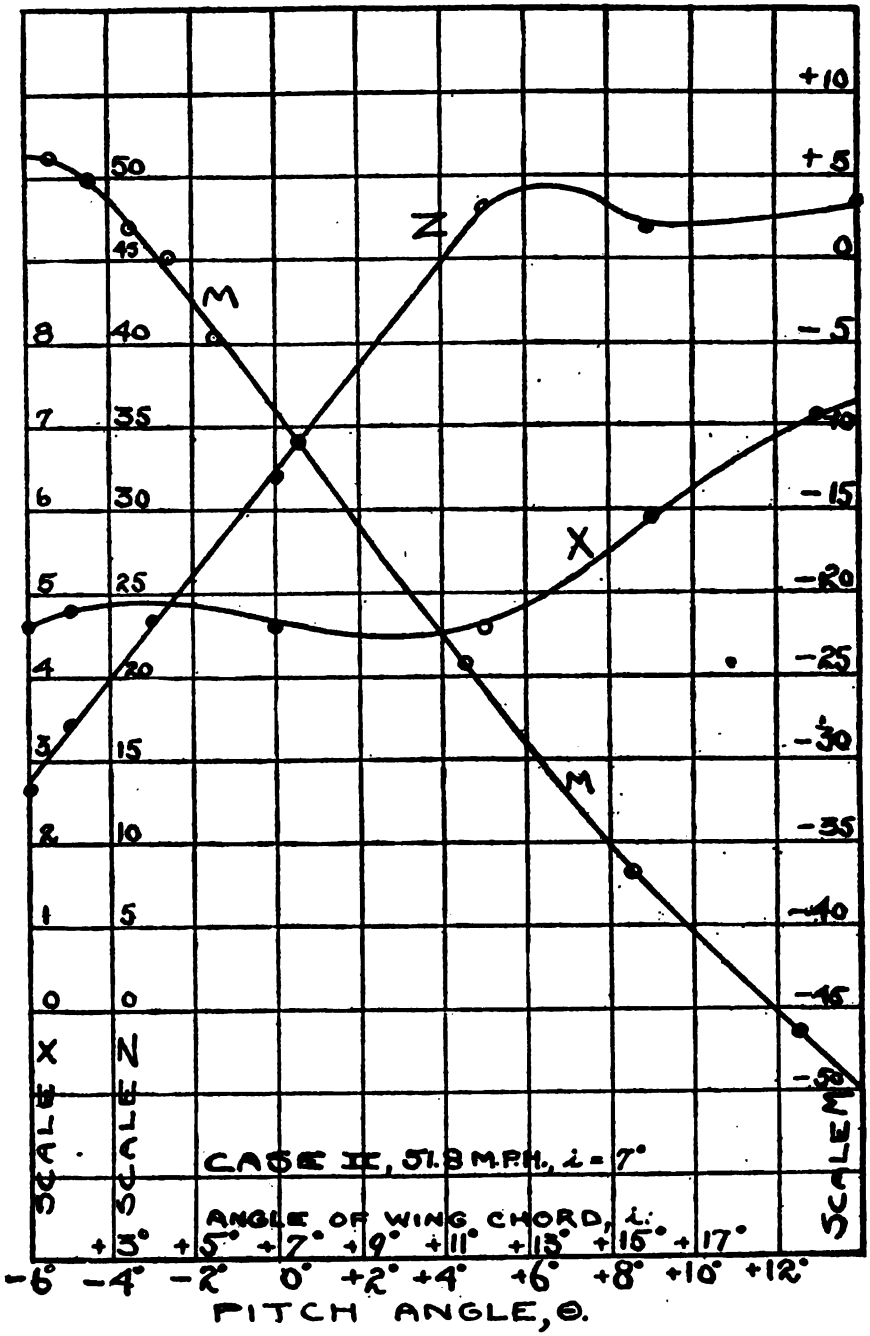


FIGURE 4.
X SCALE
Z SCALE
N SCALE
Z
M
X
CASE I, 79 M.P.H., i = +1°
ANGLE OF WING CHORD, i.
PITCH ANGLE, θ.

FIGURE 5.


+10
+5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
50
45
40
35
30
25
20
15
10
5
0
8
7
6
5
4
3
2
1
0
M
Z
X
M
SCALE X
SCALE N
SCALE M
CASE II, 51.8 M.P.H., i = 7°
ANGLE OF WING CHORD, i.
+3° +5° +7° +9° +11° +13° +15° +17°
-6° -4° -2° 0° +2° +4° +6° +8° +10° +12°
PITCH ANGLE, Θ.

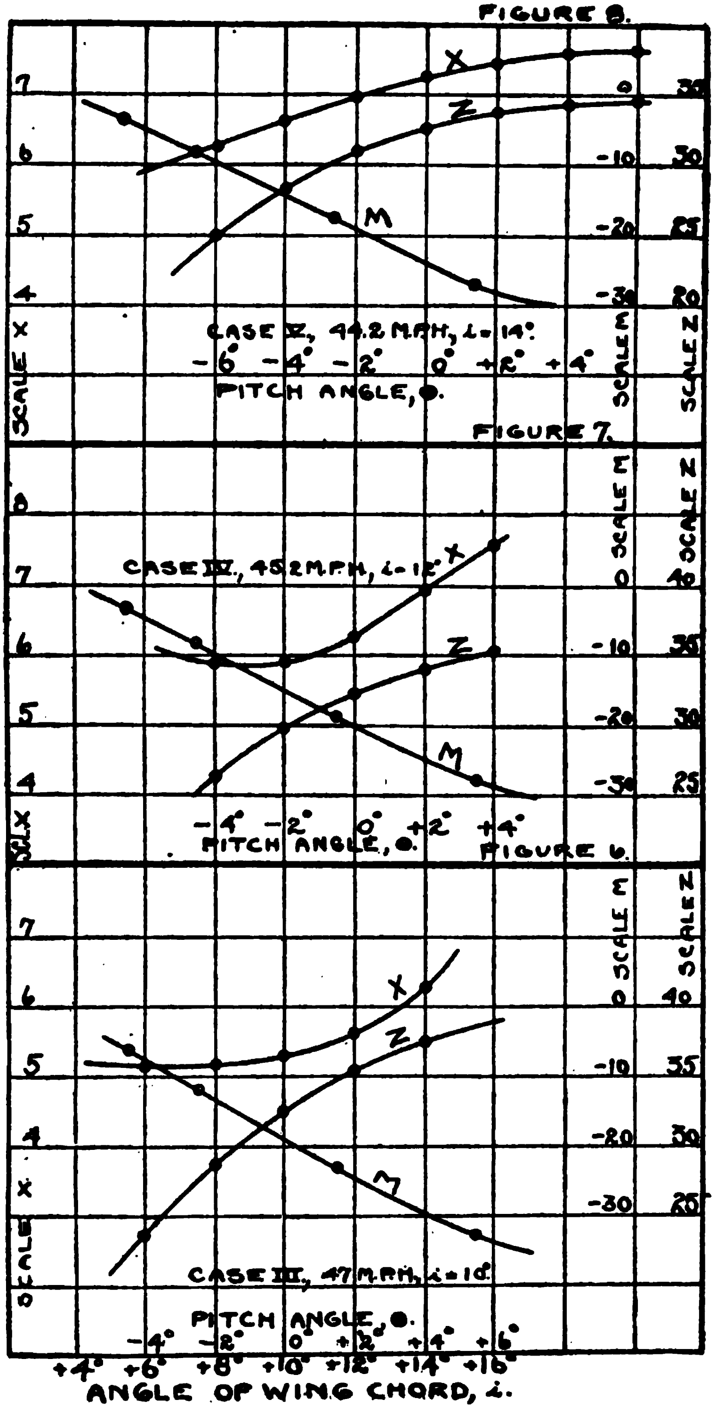
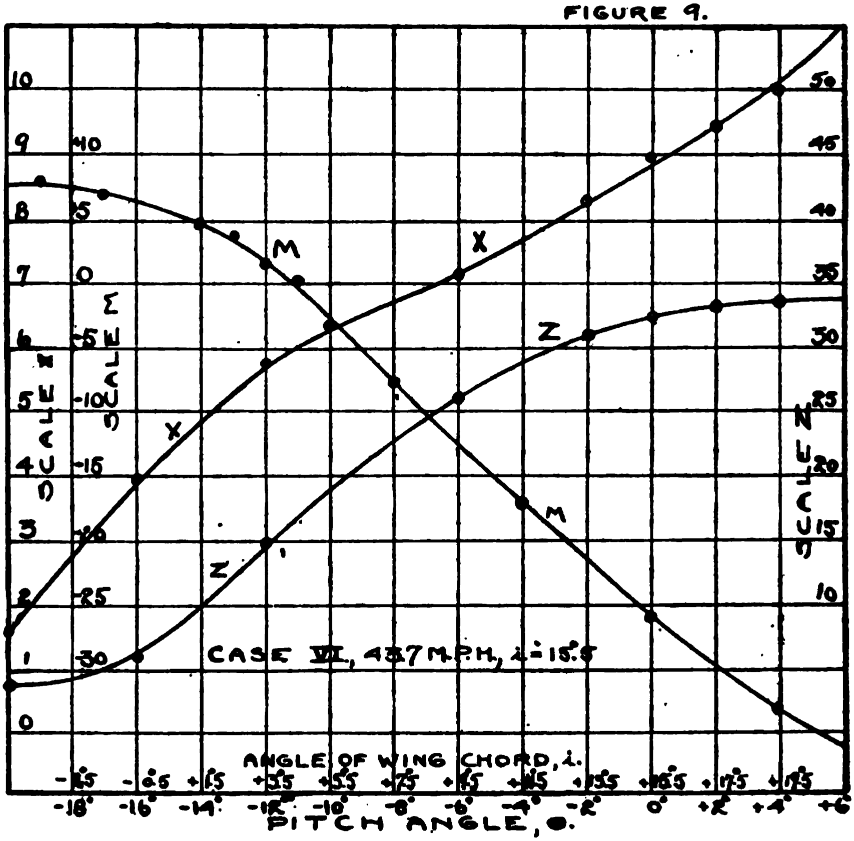


FIGURE 8.
CASE V, 44.2 M.P.H., i = 14°
-6° -4° -2° 0° +2° +4°
PITCH ANGLE, θ.
SCALE X
SCALE M
SCALE Z
FIGURE 7.
CASE IV, 45.2 M.P.H., i = 12°
-4° -2° 0° +2° +4°
PITCH ANGLE, θ.
FIGURE 6.
CASE III, 47 M.P.H., i = 10°
PITCH ANGLE, θ.
-4° -2° 0° +2° +4° +6°
+4° +6° +8° +10° +12° +14° +16°
ANGLE OF WING CHORD, i.
X
Z
M

FIGURE 9.



small oscillations, and physically represent the slope of a curve of X on a base u, w, or q.

Similarly

$$Z = Z_o + uZ_u + wZ_w + qZ_q$$
$$M = M_o + uM_u + wM_w + qM_q$$

From the conditions of equilibrium, X_o is balanced by the propeller thrust, Z_o by the pull of gravity or $Z_o = g$, and $M_o = o$. Also, Bairstow has shown that X_q and Z_q may be neglected.

X_u is the rate of change of X with change in forward speed. But since X is a function of forward speed squared we may write:

$$X_u = \frac{\Delta X_o}{\Delta U} = \frac{2X_o}{U}$$

and

$$Z_u = \frac{2Z_o}{U}$$

These coefficients may be obtained directly by calculation since $X_o = \frac{\text{Drift}}{m}$, and $Z_o = g$. For example, at 79 miles per hour, $U = -115.5$ feet per second and $Z_o = 32.2$. Then

$$Z_u = \frac{2 \times 32.2}{-115.5} = -.557$$

Also at 15°.5, $U = -63.8$ feet per second and

$$X_u = \frac{2 \times 10}{-63.8} = -.276$$

The derivatives X_w, Z_w, M_w represent the effect of a vertical component of velocity. From the well-known method of velocity composition, the vertical velocity w acts with the horizontal velocity U to cause the apparent wind to have an inclination to the horizontal of $\tan^{-1} \frac{w}{U}$. This inclination is given to the model in the wind tunnel, and X, Z, and M measured for various pitch angles.

But $\Delta\theta = \tan^{-1} \frac{w}{U} = 57.3 \frac{w}{U}$, when $\Delta\theta$ is a small angle in degrees.

$$\therefore X_w = \frac{\Delta X}{w} = \frac{57.3}{U} \cdot \frac{\Delta X}{\Delta\theta}$$

$\frac{\Delta X}{\Delta\theta}$ is the slope of a curve of X on pitch angle as base. For example, from figure 4, $\frac{\Delta X}{\Delta\theta} = \frac{-.65}{2}$ and

$$X_w = \frac{57.3}{-115.5} \cdot \frac{-.65}{2} = +0.162$$

Similar formulas are used to compute Z_w and M_w. It may be noted that the method assumes that for small oscillations, hence small changes θ, the tangent may be substituted for the actual curve. The limit of validity is obviously the range of pitch angle over which the tangent to the curve is not greatly changed. This range is usually about 4 to 8 degrees.

The values of the resistance derivatives calculated in this manner will be found tabulated later.

Article 10.

DAMPING.

The damping of pitching about the c. g. is represented by the rotary derivative M_q. For an angular velocity $\frac{d\theta}{dt} = q$, a damping moment $q M_q$ is exerted on the aeroplane.

To measure this aerodynamic damping, the special oscillating apparatus was designed which is shown by the photograph of figure 10. The model is mounted on a massive bracket which pivots about the

two points shown. Fore-and-aft arms carry counterweights which are adjusted to give a reasonable natural period. The spiral springs bear in notches on the arms by means of knife-edged shackles. The springs insure that the motion shall be oscillatory. The assumed c. g. location of the aeroplane model is arranged to be on the axis of rotation. The actual center of gravity of the apparatus is not considered.

Friction is kept small by careful design of the steel pivots, which are hardened steel points bearing in tool steel cones. The spring knife edges are glass hard. It was found that a convenient period is about one-half second. In still air the apparatus will rock more than 300 times before the amptitude is diminished by friction to one-ninth of the initial displacement.

The moment of inertia of the entire oscillating mass was calculated and then checked by an independent experimental determination.

Let:

I = moment of inertia of all oscillating parts in slug foot-units.
m' = mass of all oscillating parts in slugs.
M_o = moment of air forces on model at rest.
M_s = moment of springs at rest.
$K\theta$ = additional moment of springs when deflected.
c = c. g. of entire apparatus above pivot, feet.
θ = angle of pitch from normal attitude in radians.
$\mu_o \frac{d\theta}{dt}$ = damping moment due to friction.
$\mu_w \frac{d\theta}{dt}$ = damping moment due to wind on apparatus.
$\mu_m \frac{d\theta}{dt}$ = damping moment due to wind on model.
$cm'\theta$ = static moment due to gravity.

The equation of motion then is:

$$I\frac{d^2\theta}{dt^2} + (\mu_o + \mu_w + \mu_m)\frac{d\theta}{dt} + (K - cm')\theta + M_o - M_s = o$$

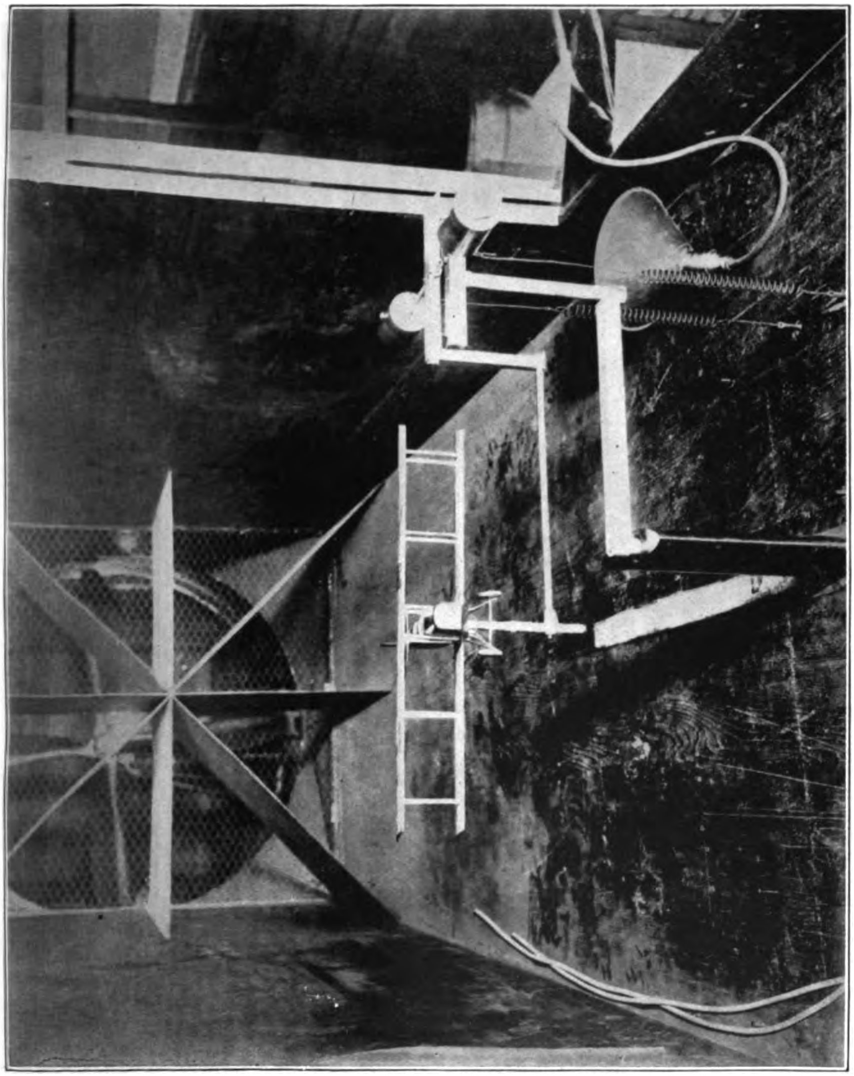
But $M_o = M_s$, by the initial condition of equilibrium. Let

$$\mu = \mu_o + \mu_w + \mu_m; \text{ then } I\frac{d^2\theta}{dt^2} + \mu\frac{d\theta}{dt} + (K - cm')\theta = o$$

The solution of this equation is well known to be:

$$\theta = C_e^{\frac{-\mu t}{2I}} \cos\left\{t\sqrt{(K - cm')\frac{1}{I} - \frac{\mu^2}{4I^2}} + \alpha\right\},$$

where O and α are arbitrary constants. If time be counted when the amplitude of swing is a maximum then $\cos\{-\} = 1$, and $\theta = \theta_o$, the initial displacement. Also if the number of beats be counted by



observing the times for succeeding maxima, a plot of amplitude on time will have for its equation the simple form:

$$\theta = \theta_o e^{\frac{-\mu t}{2I}}$$

The coefficient μ is the logarithmic decrement of the oscillation and must be numerically positive to insure that the oscillation dies out with time.

The apparatus was fitted with a small reflecting prism by which a pencil of light was deflected toward a ground glass plate set in the roof of the tunnel. Nine lines spaced 0.2 inch were ruled on this plate. With the model at rest the beam of light was brought to a sharp focus on the line marked zero. By means of a trigger the observer started an oscillation of the model, and the spot of light was observed to oscillate across the scale. The time, t, was observed in which an oscillation was damped from an amplitude of 9 to an amplitude of 1, for example.

Then: $log_e\frac{\theta_o}{\theta} = \frac{\mu}{2I}t = log_e 9$, and knowing I and t, μ is calculated.

Preliminary tests showed that the same value of μ was obtained whether the timing stopped at $\theta = 5, 4, 3, 2$, or 1.

Oscillation tests were made at five wind velocities varying from 5 to 35 miles per hour. The coefficient μ appeared to vary approximately as the first power of the velocity.

Similar tests were made with the model for no wind to determine μ_o, which may be said to be due almost wholly to friction and very slightly to the damping of apparatus and model moving through the air.

Likewise μ_w was obtained by oscillating the apparatus without model in winds from 5 to 35 miles per hour.

The coefficient μ_m has the dimensions [1] $\rho l^4 V$, where ρ is density of air, l a linear dimension, and V the velocity of the wind. To convert μ_m to M_q for the full-size machine at full speed, multiply by the fourth power of 24, the scale, and by the ratio of full speed to model speed.

The numerical results of tests of the pitching oscillation follow. Note that the damping of the pitching falls off for low speeds. This contributes to the difficulty of providing sufficient stability at low speeds.

In the tables following, the number of beats, n, is recorded as a general check and is not used. Recorded values of n and t are the means of three or five separate observations.

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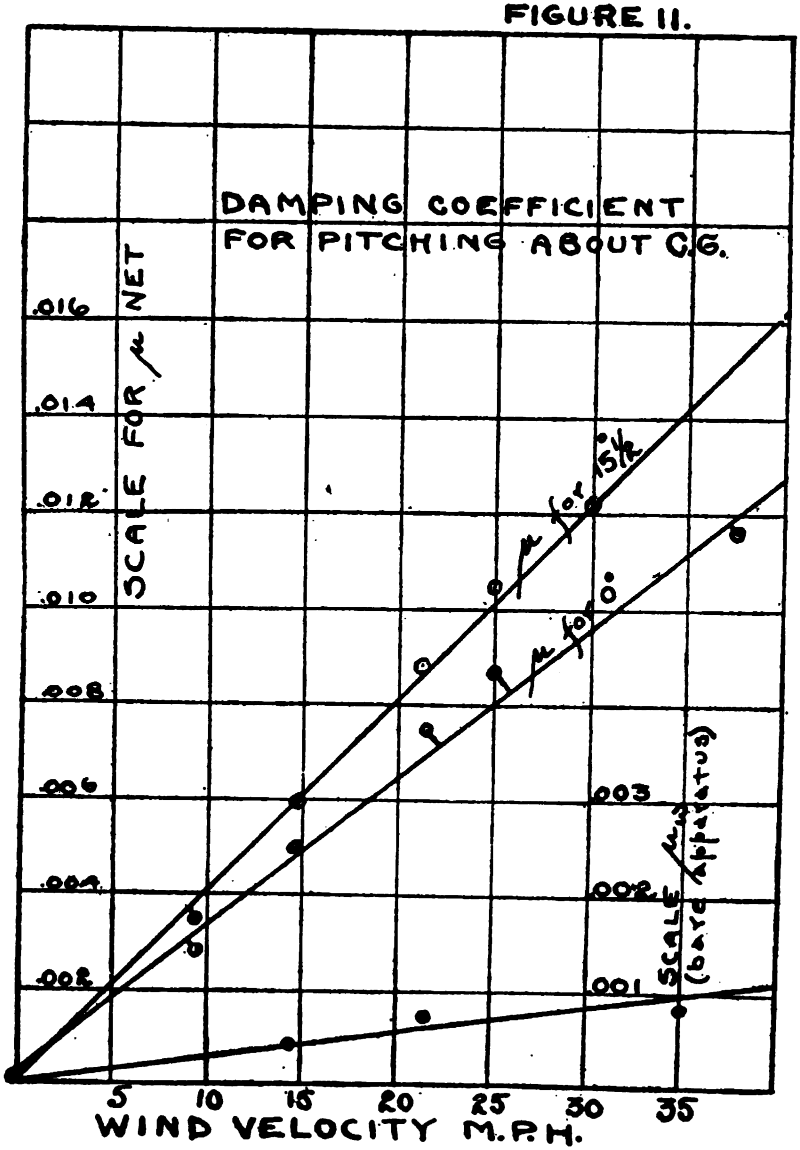
[1] Bairstow, loc. cit., p. 176.

FIGURE 11.


DAMPING COEFFICIENT
FOR PITCHING ABOUT C.G.
SCALE FOR μ NET
.016
.014
.012
.010
.008
.006
.004
.002
μ for 15°
μ for 0°
.003
.002
.001
SCALE μ
(bare apparatus)
5
10
15
20
25
30
35
WIND VELOCITY M.P.H.

PITCHING OSCILLATION TESTS.

I model and apparatus = 0.04195
I apparatus = .0368

Apparatus.

Wind velocity, miles....	0	14.7	21.4	35	
n beats counted........	350	253	210	186	
t seconds................	168	120	100	90	
μ........................	.00096	.00135	.00162	.00180	
μ_w (less zero)............	0	.00039	.00066	.00084	Use faired values below.

Apparatus and model with wing chord 1° to wind.

V miles......................	0	9.5	14.7	21.3	25	30	37.3
n beats.......................	300	90	56	40	35	32	27
t seconds....................	160	45	28.5	20	17.5	16	13.5
μ gross.......................	.00115	.00410	.00646	.0092	.0105	.0115	.0137
μ_0 friction..................	.00096	.00096	.00096	.0010	.0010	.0010	.0010
μ_w apparatus................	0	.00035	.00040	.0006	.0007	.0009	.0011
μ_m net.......................	.00019	.00284	.0054	.0076	.0088	.0096	.0117

But $\mu_m = -m\ M_q$ when reduced to full size and 79 miles per hour and mass of 55.9 slugs.

$$\therefore M_q = -.0096 \times (24)^4 \times (79/30) \times 1/55.9 = -150.0$$

or for

$$U = -114 \text{ foot-seconds}, \quad M_q = 1.32\ U$$

Apparatus and model with wing chord 15.5° to wind.

V..........................	9.1	14.7	21.4	25	30	37.5
n...........................	75	50	35	30	25	19
t...........................	38.5	25.0	17.5	15	13	9
μ gross......................	.0048	.0074	.0105	.0123	.0142	.0205
μ_m net......................	.0035	.0060	.0089	.0106	.0123	.0184

$$M_q = -.0123 \times (24)^4 \times (43.7/30) \times 1/55.9 = -106$$

or

$$M_q = 1.66\ U \text{ where } U \text{ is } -64 \text{ foot-seconds, or 43.7 miles.}$$

The computed values of μ_m, the model damping coefficient, are plotted on figure 11. It appears that μ_m is approximately a linear function of the velocity, as would be expected, and the conversion to full scale, full speed, is made as indicated above.

The damping coefficient is not greatly different for different attitudes, and the following values are obtained by interpolation:

Angle of wing chord to wind.	V.	U.	M_q.
+1°	79.0	−115.5	1.30 U = −150
7°	51.8	− 75.8	1.49 U = −113
10°	47.0	− 68.8	1.55 U = −108
12°	45.2	− 66.2	1.59 U = −106
14°	44.2	− 64.8	1.63 U = −106
15.5°	43.7	− 64.0	1.66 U = −106

Article 11.

RADIUS OF GYRATION.

For the radii of gyration of the fully loaded aeroplane we are indebted to Dr. A. F. Zahm. The actual aeroplane, complete with gasoline, water, pilot, passenger, and other weights in place, was suspended from a beam by a chain. The center of gravity was first located by an inclining method. The machine was then made to oscillate in pitch about the point of attachment of the upper end of the chain. Light guys were run to tail and wing tips to insure that the chain and aeroplane moved as a rigid body.

Let the distance from center of gravity to point of suspension be denoted by h, p the natural period of oscillation in seconds, K_B the radius of gyration in feet about the Y axis or axis of pitch, then

$$K_B^2=\left(\frac{gh}{4\pi^2}\right)p^2-h^2$$

By observation $h=12.2$ feet, $p=60/14$ seconds.

$$K_B^2=34,\ K_B=5.8 \text{ feet.}$$ [1]

Article 12.

ROUTH'S DISCRIMINANT.

Bryan [2] has shown that the character of the longitudinal motion of an aeroplane may be investigated with reference to the roots of a biquadratic equation of the form:

$$A\lambda^4+B\lambda^3+C\lambda^2+D\lambda+E=0$$

The equations of motion may be considered of the form $\Theta=Ke^{\lambda t}$ where K is some constant. For stability the quantity λ must be negative if real, or have its real part negative if complex, in order that the amplitude of the motion will diminish with time.

The condition that the real roots and real parts of imaginary roots of a biquadratic equation with constant coefficients shall be negative is that the coefficients A, B, C, D, E shall each be positive as well as the quantity $BCD-AD^2-B^2E$. The latter is commonly known as Routh's [3] discriminant.

The constant coefficients A, B, C, D, E, are functions of the constants of the aeroplane at the normal flying attitude, i. e., the following: X_u, X_w, X_q, Z_u, Z_w, Z_q, M_u, M_w, M_q, U, and K_B^2. These are resistance and rotary derivatives, velocity, and radius of gyration. For a given attitude and for small oscillations about that attitude, it is considered that these quantities are constant. For simplicity it is here assumed that normal flight takes place in a horizontal plane and the inclination of the flight path and consequent components of gravity in the axes of X and Z are eliminated. Also X_q and Z_q are

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[1] It is of interest to note that the radius of gyration for rolling was estimated to be 6.2 feet.
[2] Stability in Aviation.
[3] Advanced Rigid Dynamics, E. J. Routh.

neglected as unimportant and M_u is zero by the conditions of equilibrium. For the computation of Routh's discriminant we require to know, then, only those quantities which have been so far determined, and which are assembled below for the different cases investigated.

Formulæ for the coefficients A, B, C, D, E are given by Bairstow and are used here, but making Θ, X_q, Z_q, and M_u zero. They are copied in simplified form for reference.

$$A = K_B^2$$

$$B = -(M_q + X_u K_B^2 + Z_w K_B^2)$$

$$C = \begin{vmatrix} Z_w, & U \\ M_w, & M_q \end{vmatrix} + X_u M_q + K_B^2 \begin{vmatrix} X_u, & X_w \\ Z_u, & Z_w \end{vmatrix}$$

$$D = -\begin{vmatrix} X_u, & X_w, & 0 \\ Z_u, & Z_w, & U \\ M_u, & M_w, & M_q \end{vmatrix}$$

$$E = -gM_w Z_u$$

Article 13.

BAIRSTOW'S APPROXIMATE SOLUTION.

From consideration of the usual relative numerical values of the coefficients of the biquadratic, Bairstow has shown that the equation may be factored to a first approximation and put into the following form:

$$\left(\lambda^2 + B/A\lambda + C/A\right)\left(\lambda^2 + \left[D/C - \frac{BE}{C^2}\right]\lambda + \frac{E}{C}\right) = 0.$$

in which the first factor represents a very short oscillation, which in most aeroplanes rapidly dies out and is of no importance. The second factor represents a relatively long oscillation involving an undulatory flight path with changes in pitch, forward speed, and altitude. The long oscillations should diminish in amplitude with time, in which case the motion is stable and the aeroplane will return to its original normal flight attitude if temporarily deviated therefrom by accidental cause. The motion is unstable if the long oscillation increases in amplitude with time. It will be shown that the aeroplane under investigation is stable at high speeds and unstable at very low speeds. It is believed that this is true of all aeroplanes.

Case I.

i = incidence, wing chord to wind $+1°$.

Velocity $V = 79$ miles. $U = -115.5$ foot-seconds.
$m = 55.9$ slugs, $K_B^2 = 34$.

X_u −.128 X_w +.162 M_w +1.74
Z_u −.557 Z_w −3.95 M_q −150

$$\left.\begin{aligned} A &= +\ 34 \\ B &= +289 \\ C &= +834 \\ D &= +115 \\ E &= +\ 31 \end{aligned}\right\} BCD - AD^2 - B^2E = +18\times10^6 \textit{ stable.}$$

Short oscillation: $\lambda^2+8.5\lambda+24.5=0$
$\lambda=-4.25\pm2.54i$

$p=\text{period}=\dfrac{2\pi}{2.54}=2.5$ seconds.

$t=$time to damp 50 per cent$=\dfrac{0.69}{4.25}=.16$ second.

Long oscillation: $\lambda^2+.125\lambda+.0374=0$
$\lambda=-.063\pm.183i$
$p=34.3$ seconds, $t=10.8$ seconds.

The short oscillations are unimportant. The long oscillations are easy and strongly damped. The aeroplane should be very steady at this speed.

CASE II.

$i=7°$, $V=51.8$ miles, $U=-75.9$ foot-seconds.

$X_u-.121$ $X_w+.113$ $M_w+2.45$
$Z_u-.849$ $Z_w-2.26$ M_q-113

$$\left.\begin{array}{l}A=+\ 34.0\\ B=+194.0\\ C=+467.0\\ D=+\ 64.3\\ E=+\ 67.0\end{array}\right\}BCD-AD^2-B^2E=+32\times10^5\ \textit{stable.}$$

Short oscillation: $\lambda^2+5.7\lambda+15.9=0$
$\lambda=-2.85\pm2.33i$
$p=2.7$ seconds
$t=.24$ second to damp 50 per cent.

Long oscillation: $\lambda^2+.078\lambda+.143=0$
$\lambda=-.039\pm.377i$
$p=16.7$ seconds
$t=17.7$ seconds to damp 50 per cent.

The period is shorter than at high speed and the damping less. The aeroplane should therefore be less comfortable.

CASE III.

$i=10°$, $V=47$ miles, $U=-68.8$ foot-seconds.

$X_u-.151$ $Z_u-.936$ $M_w+2.50$
$X_w-.075$ $Z_w-1.46$ M_q-108

$$\left.\begin{array}{l}A=+\ 34\\ B=+165\\ C=+355\\ D=+\ 42.5\\ E=+\ 75.3\end{array}\right\}BCD-(AD^2+B^2E)=3.8\times10^5\ \textit{stable.}$$

Short oscillation: $\lambda^2+\ 4.85\lambda+10.44=0$
$\lambda=-2.42\pm2.12$

$p=2.96$ seconds.
$t=\ .28$ second to damp 50 per cent.

Long oscillation: $\lambda^2+\ .021\lambda+.212=0$
$\lambda=-.011\pm.460i$

$p=13.71$ seconds.
$t=62.7$ seconds to damp 50 per cent.

This oscillation is rapid and but slightly damped, and would probably be uncomfortable. The stability is slight and wind gusts or external disturbances, if recurrent, might cause trouble.

CASE IV.

$i=12°$, $V=45.2$ miles $U=-66.2$ foot-seconds.

$$X_u-.189 \quad Z_u-.972 \quad M_w+2.15$$
$$X_w-.236 \quad Z_w-.736 \quad M_q-106$$

$$\left.\begin{array}{l} A=+34 \\ B=+137.5 \\ C=+243 \\ D=+17.4 \\ E=+67.2 \end{array}\right\} BCD-AD^2-B^2E=-7\times10^5 \text{ UNSTABLE.}$$

Short oscillation: $\lambda^2+4.04\lambda+7.14=0$
$\lambda=-2.02\pm1.75i$

$p=3.59$ seconds.
$t=.342$ second to damp 50 per cent.

Long oscillation: $\lambda^2-.985\lambda=.276=0$
$\lambda=+.043\pm.524i$

$p=12.0$ seconds.
$t=16.0$ seconds to double amplitude.

The machine is frankly unstable and the pilot dare not release his elevator control.

CASE V.

$i=14°$, $V=44.2$ miles, $U=-64.8$ foot-seconds.

$$X_u-.223 \quad Z_u-.993 \quad M_w+1.99$$
$$X_w-.132 \quad Z_w-.553 \quad M_q-106$$

$$\left.\begin{array}{l} A=+34 \\ B=+134 \\ C=+213 \\ D=+28 \\ E=+63.6 \end{array}\right\} BCD-AD^2-B^2E=-3.7\times10^5 \text{ UNSTABLE.}$$

CASE VI.

$i=15.5°$ $V=43.7$ miles, $U=-63.8$ foot-seconds.

$$X_u-.276 \quad Z_u-1.01 \quad M_w+2.02$$
$$X_w-.292 \quad Z_w-.673 \quad M_q-106$$

$$\left.\begin{array}{l} A=+34 \\ B=+138 \\ C=+226 \\ D=+24.2 \\ E=+65.7 \end{array}\right\} BCD-AD^2-B^2E=-5\times10^5 \text{ UNSTABLE.}$$

Short oscillation: $\lambda^2+4.06\lambda+6.65=0$
$\lambda=-2.03\pm1.59i$

$p=3.95$ seconds, period.
$t=.34$ seconds to damp 50 per cent.

Long oscillation: $\lambda^2+.071\lambda+.291=0$
$\lambda=+.0358\pm.541i$

Real part of λ' is here positive, indicating an oscillation increasing with time.

$$p=\frac{2\pi}{.541}=11.6 \text{ seconds.}$$

$$t=\frac{.069}{.0358}=19.3 \text{ seconds to } \textit{double} \text{ amplitude.}$$

The motion is both rapid in period and rapidly increasing in amplitude. Indeed the amplitude is doubled in two swings. This aeroplane, if left to itself, would be highly unstable.

Article 14.

VARIATION OF LONGITUDINAL STABILITY WITH SPEED.

Preliminary to consideration of the action of gusts on an inherently stable aeroplane, it was desired to analyze the motion in still air of a machine which could be called inherently stable longitudinally. It has been found above that a typical aeroplane becomes less stable at low speeds until real instability results. This result is somewhat unexpected in view of the curves of pitching moment M, which indicated static stability at all possible attitudes up to and including horizontal flight at $+15°.5$. In other words, M_w is positive for all cases. The instability comes about on account of the rapid rate of increase of drift at large angles causing X_w to change sign, and on account of the less rapid rate of increase of lift, causing Z_w to become small at high angles of pitch. Furthermore, M_q diminishes at low speed.

From the speed power curves on figure 3, it appears that for angles greater than 10°, we are on the part of the power curve which requires more power to go slower, "region of reversed controls." This region is now found to be dynamically unstable so that controlled flight only is possible here. But with reversed controls this is doubly dangerous.

The frequency of accidents at low speeds, following the recent demand for a wide speed range, confirms this impression of the danger of low speeds when approaching a critical angle and speed. The critical angle for instability is clearly an angle less than the possible maximum for flight.

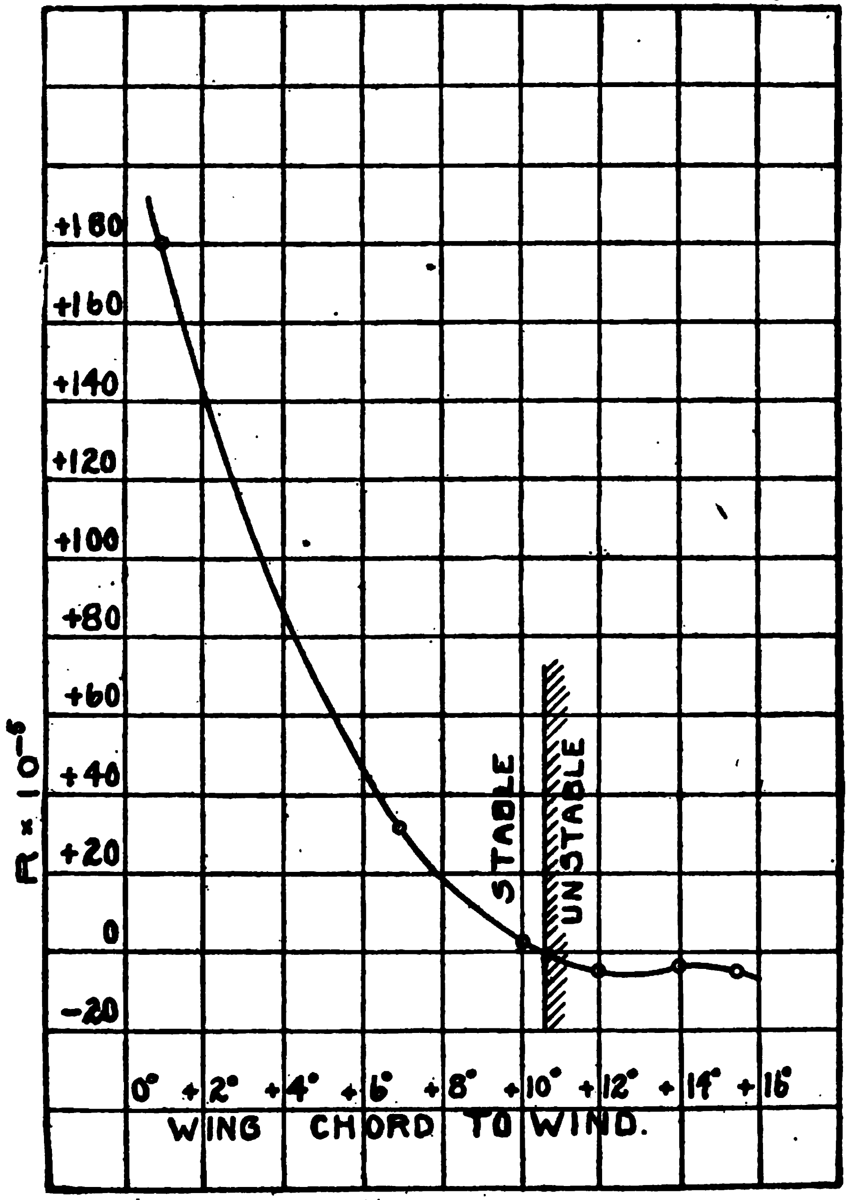
A fair measure of the relative stability at various speeds may be had by noting the following tabulation of the values of Routh's discriminant, denoted by R:

Velocity in miles.	Wind chord to wind.	R.	
79.0	1°	$+180 \times 10^5$	Stable.
51.8	7°	$+32 \times 10^5$	
47.0	10°	$+3.8 \times 10^5$	
45.2	12°	-7×10^5	Unstable.
44.2	14°	-3.7×10^5	
43.7	15.5°	-5×10^5	

The table is reproduced graphically on figure 12.

A similar investigation for lateral stability fails to show any marked change with speed, as would be expected since speed depends on pitch angle and the factors which make or unmake lateral stability are but slightly affected by angle of pitch.

FIG. 12.



ROUTH'S DISCRIMINANT,
VARIATION WITH ATTITUDE.

REPORT No. 1.

PART 2.

THEORY OF AN AEROPLANE ENCOUNTERING GUSTS.

By EDWIN BIDWELL WILSON.

ARTICLE 1.

INTRODUCTION.

The notation here used will be in the main that of Bairstow. (Technical Report of the Committee for Aeronautics for the Year 1912–13, p. 143.) As, however, Bairstow changes his notation in the first few pages of his report, we shall begin at the start with some departures from him.

If x, y, z are moving axes directed, respectively, backward, to the left, and upward relative to the driver; if u', v', w' be linear velocities, and p', q', r' be angular velocities, resolved along these axes; and if X', Y', Z' be forces, and L', M', N' be moments of forces (measured per unit mass of the aeroplane); then the dynamical equations of motion are

$$du'/dt + w'q' - v'r' = X', \tag{1a}$$

$$dv'/dt + u'r' - w'p' = Y', \tag{1b}$$

$$dw'/dt + v'p' - u'q' = Z', \tag{1c}$$

$$dh_1/dt - r'h_2 + q'h_3 = mL', \tag{2a}$$

$$dh_2/dt - p'h_3 + r'h_1 = mM', \tag{2b}$$

$$dh_3/dt - q'h_1 + p'h_2 = mN', \tag{2c}$$

where m is the mass and

$$h_1 = p'A - q'F - r'E, \tag{3a}$$

$$h_2 = q'B - r'D - p'F, \tag{3b}$$

$$h_3 = r'C - p'E - q'D, \tag{3c}$$

are the components of angular momentum,—the quantities A, B, C being the moments and D, E, F the products of inertia relative to the moving axes fixed in the body.

The symmetric aeroplane will alone be considered here;

$$D=F=0. \tag{4}$$

If the machine is in uniform horizontal flight, all the forces, moments, linear velocities and angular velocities except u' vanish, and $u'=U$, a negative quantity in magnitude equal to the uniform velocity. (The precise backward direction of the x-axis is that which is horizontal in uniform flight, and hence by this definition the direction of this axis, and of the z-axis, varies in the aeroplane with the speed.)

If the motion is slightly disturbed, the velocities take the values

$$u'=U+u, v'=v, w'=w, p'=p, q'=q, r'=r, \tag{5}$$

where u, v, w, p, q, r are small. The products of these small quantities are neglected, as in all discussions of small oscillations, and the equations take the form

$$du/dt=X',\ \ dv/dt+Ur=Y',\ \ dw/dt-Uq=Z', \tag{6}$$

$$Adp/dt-Edr/dt=mL', Bdq/dt=mM', Cdr/dt-Edp/dt=mN'. \tag{7}$$

In uniform motion the forces and moments all vanish. For the disturbed motion they are small and may be expressed linearly in terms of u, v, w, p, q, r. The forces are due to three sources: 1° the propeller thrust, 2° gravity, 3° the air. We shall assume that the propeller thrust (and moment, if any, arising from it) is constant; i. e., the motor is supposed to speed up or slow down under changed conditions so as to deliver a constant thrust. If θ and φ are the small pitch and roll, the components of gravity are $g\theta$, $-g\varphi$, $-g$ (see Bairstow, 144, $7u-w$), and its moments are zero because the C. G. is taken as origin. The air forces and moments may be written as X, Y, Z, L, M, N and developed as

$$X=X_0+X_uu+X_vv+X_ww+X_pp+X_qq+X_rr, \tag{8}$$

where X_u, X_v, ... are the "resistance derivatives" taken for the relative velocity of machine and wind. (X_0 and the propeller thrust cancel, so do Z_0 and g; Y_0, L_0, M_0, N_0 vanish.)

In the symmetric aeroplane half the resistance derivatives vanish and the six equations of motion separate into two sets of three each, one set for the longitudinal, the other for the transverse motion. These equations are (Bairstow, 148, 13 and 14 with $\Theta=0$) for longitudinal motion,

$$du/dt=g\theta+X_uu+X_ww+X_qq, \qquad (9a) \text{ see } (1a)$$

$$dw/dt=Uq+Z_uu+Z_ww+Z_qq, \qquad (9b) \text{ see } (1c)$$

$$B/m.\ dq/dt=M_uu+M_ww+M_qq, \qquad (9c) \text{ see } (2b)$$

and, for transverse motion,

$$dv/dt = -g\varphi - Ur + Y_v v + Y_p p + Y_r r, \quad (10a) \text{ see } (1b)$$

$$A/m.\, dp/dt - E/m.\, dr/dt = L_v v + L_p p + L_r r, \quad (10b) \text{ see } (2a)$$

$$C/m.\, dr/dt - E/m.\, dp/dt = N_v v + N_p p + N_r r. \quad (10c) \text{ see } (2c)$$

The integration of these equations gives the free oscillations of the aeroplane.

Article 2.

LONGITUDINAL MOTION IN SMALL GUSTS.

A gust if not too severe may be treated by the method of forced oscillations. If the aeroplane is traveling on an irregular wind, we may regard the average wind velocity relative to the machine as that which should be used in the computation of the resistance derivatives, and we may regard the departures of the actual relative velocity from the mean as small quantities inducing additional forces into the equations of motion.

Suppose first a head-on gustiness. This would introduce an extra term of the form $X_u u$ into the first equation, $Z_u u$ in the second, and so on. If, as a result of the gust, the machine tilted appreciably, the originally head-on gust would no longer be head-on, but would have components u_1, w_1 and give rise to the term $X_u u_1 + X_w w_1$ in the first equation. It is clear, however, that under the hypothesis of small oscillations, w_1 would remain small of the second order relative to u_1. The term $X_w w_1$ could then be neglected relative to $X_u u_1$, unless X_w much exceeded X_u.

We should in general allow a gust to have components $u_1, v_1, w_1, p_1, q_1, r_1$ relative to the axes. This would take into account any possible rotational motion in the gust. The rotational motion of a gust may be quite small. In the discussion by Glazebrook (Aeronautical Journal, July, 1914, pp. 272–301) nothing is accomplished relative to rotational gusts. Yet it may well be that the rotational element is of great importance. For the rotary derivatives, in the case of the machine whose derivatives are tabulated by Bairstow (loc. cit., 159), are large. Thus a term $M_q q_1 = -210 q_1$ would be comparable with $X_u u_1 = -0.14 u_1$ if q_1 were 1/700 of u_1; i. e., if the gust were a uniform whirl of radius 700 feet. In the same way L_p is large. In the machine that will be discussed in what follows M_q is also large, viz., -150.

The equations for the longitudinal motion in a general gust are (see 9a–c)

$$du/dt - g\theta - X_u u - X_w w - X_q q = X_u u_1 + X_w w_1 + X_q q_1. \quad (11a)$$

$$dw/dt - Uq - Z_u u - Z_w w - Z_q q = Z_u u_1 + Z_w w_1 + Z_q q_1. \quad (11b)$$

$$B/m\; dq/dt - M_u u - M_w w - M_q q = M_u u_1 + M_w w_1 + M_q q_1. \quad (11c)$$

The solution of these equations consists of two parts: 1° the so-called complementary function which gives the natural oscillations, 2° the particular integral which gives the forced oscillations due to the gust. To effect a solution for the particular integral, we must

make some assumption as to the value of the components u_1, w_1, q_1 of the gusts as functions of the time. Before making such an assumption for the particular integral, the solution by the "operational" method may be indicated. (See Wilson, Advanced Calculus, p. 223.)

Let D denote differentiation. The equations may be written

$$(D-X_u)u-X_w w-(X_q D+g)\theta \qquad = X_u u_1+X_w w_1+X_q q_1, \qquad (12a)$$

$$-Z_u u+(D-Z_w)w-(Z_q+U)D\theta = Z_u u_1+Z_w w_1+Z_q q_1, \qquad (12b)$$

$$-M_u u-M_w w+(k^2_B D^2-M_q D)\theta = M_u u_1+M_w w_1+M_q q_1, \qquad (12c)$$

where $k^2_B = B/m$. These equations are solved algebraically by multiplying by the proper cofactor determinants and adding. Then

$$\begin{vmatrix} D-X_u & -X_w & -(X_q D+g) \\ -Z_u & D-Z_w & -(Z_q+U)D \\ -M_u & -M_w & k^2_B D^2-M_q D \end{vmatrix} u = \begin{vmatrix} X_u & -X_w & -(X_q D+g) \\ Z_u & D-Z_w & -(Z_q+U)D \\ M_u & -M_w & k^2_B D^2-M_q D \end{vmatrix} u_1$$

$$+\begin{vmatrix} X_w & -X_w & -(X_q D+g) \\ Z_w & D-Z_w & -(Z_q+U)D \\ M_w & -M_w & k^2_B D^2-M_q D \end{vmatrix} w_1 \qquad (13)$$

$$+\begin{vmatrix} X_q & -X_w & -(X_q D+g) \\ Z_q & D-Z_w & -(Z_q+U)D \\ M_q & -M_w & k^2_B D^2-M_q D \end{vmatrix} q_1 .$$

or, if the determinant on the left be denoted by Δ,

$$\Delta u = \begin{vmatrix} X_u & -X_w & -(X_q D+g) \\ Z_u & D-Z_w & -(Z_q+U)D \\ M_u & -M_w & k^2_B D^2-M_q D \end{vmatrix} u_1 \qquad (14a)$$

$$+D\begin{vmatrix} X_w & -(X_q D+g) \\ M_w & k^2_B D^2-M_q D \end{vmatrix} w_1 + \begin{vmatrix} X_q & -X_w & -g \\ Z_q & D-Z_w & -UD \\ M_q & -M_w & k^2_B D^2 \end{vmatrix} q_1 .$$

There are similar equations for w and θ, namely,

$$\Delta u = \begin{vmatrix} D-X_u & X_w & -(X_q D+g) \\ -Z_u & Z_w & -(Z_q+U)D \\ -M_u & M_w & k^2_B D^2-M_q D \end{vmatrix} w_1 \qquad (14b)$$

$$+D\begin{vmatrix} Z_u & -(Z_q+U)D \\ M_u & k^2_B D^2-M_q D \end{vmatrix} u_1 + \begin{vmatrix} D-X_u & X_q & -g \\ -Z_u & Z_q & -UD \\ -M_u & M_q & k^2_B D^2 \end{vmatrix} q_1,$$

$$\Delta\theta = \begin{vmatrix} D-X_u & -X_w & X_q \\ -Z_u & D-Z_w & Z_q \\ -M_u & -M_w & M_q \end{vmatrix} q_1 \qquad (14c)$$

$$+D\begin{vmatrix} D-Z_w & Z_u \\ -M_w & M_u \end{vmatrix} u_1 + D\begin{vmatrix} D-X_u & X_w \\ -M_u & M_w \end{vmatrix} w_1 .$$

The general (literal) integration of these equations would be so complicated as to be useless. We shall make use of the formulas only after simplification by the insertion of numerical data.

Possible methods of treating gusts.—The only treatment of gusts which I have seen is that described somewhat popularly by Glazebrook (loc. cit.). He seems to state, as the main method of attack, that of small differences whereby it is assumed that the involved time over which the motion is to be studied is divided into small parts, and that the atmospheric conditions remain constant during each of these parts. By then regarding the differential equations of motion as equations in differences of the following form,

$$\Delta u' = (X' - w'q' + v'r')\Delta t, \text{ etc.},$$

$$\Delta h_1 = (mL' + r'h_2 - q'h_3)\Delta t, \text{ etc.},$$

it is possible to compute, through a series of intervals Δt, the approximate positions of the aeroplane. This method is, as Glazebrook states, exceedingly tedious, for Δt must be taken very small, indeed only a small part of a second in the case of a sharp gust, in order that the solution may be even approximately satisfactory for the differential equations. Moreover, the whole calculation apparently has to be done from the beginning for each new type of gust which one desires to study. The method, however, is applicable in all generality irrespective of the stability of the aeroplane.

The reason that I have chosen to operate on the basis of small oscillations is that after a certain amount of preliminary calculation has been accomplished my formulas will enable me to treat very rapidly a series of very different types of gusts. My method is not applicable, of course, to machines which are not stable, for the oscillations could not remain small with such machines, but it is probably doubtful whether the motion of the unstable aeroplane in a gusty wind is of very great importance, as the instability of the machine is not unlikely to cause indeterminately violent motions on relatively small gusts. I have tried to devise methods which would enable me to use graphical apparatus for obtaining the solutions here desired, but have been unable to throw the equations into a form which lends itself to such methods.

Moreover, the coefficients which enter into the equations and into the solutions at all stages of the work are of such varying magnitudes that it is difficult to obtain any reasonably accurate results. It seems impossible—I have not yet succeeded in avoiding the difficulty—to eliminate the occasional necessity of subtracting numbers which are nearly equal in magnitude; thus the accuracy of the figures is, after subtraction, seriously impaired. As I was aware that the data furnished me were probably not accurate to three figures, I first made the calculations with slide-rule accuracy, only to find that the final results became wholly illusory, owing to the difficulty just mentioned. I have therefore had to recompute everything with 4-place logarithm tables. Most of the figures which occur in the work are therefore 4-place numbers. Those which appear to have only three significant figures generally have the fourth figure zero when occurring in formulas containing 4-place numbers. In the calculations toward the end of the research the 4-figure accuracy has become reduced to three or two figure accuracy, but it did not seem best systematically to reduce the numbers by the omission of two figures, although this reduction has occasionally been made in final calculations.

Article 3.

NUMERICAL EQUATIONS FOR HIGH SPEED.

The data for high speed are (see Hunsaker, p. 47):

$$\begin{array}{lll} X_u = -0.128, & X_w = +0.162, & X_q = 0 \\ Z_u = -0.557, & Z_w = -3.95, & Z_q = 0 \\ M_u = 0, & M_w = +1.74, & M_q = -150 \\ B/m = k^2_B = 34, & U = -115.5, & g = 32.17 \end{array} \tag{15}$$

The cofactors δ in the determinant Δ are—

$$\begin{vmatrix} D-Z_w & -(Z_q+U)D \\ -M_w & k^2_B D^2 - M_q D \end{vmatrix} = \begin{vmatrix} D+3.95 & 115.5D \\ -1.74 & 34D^2+150D \end{vmatrix}$$

$$= 34D^3 + 284.3D^2 + 793.5D = \delta_{11}$$

$$\begin{vmatrix} -M_w & k^2_B D^2 - M_q D \\ -X_w & -(X_q D+g) \end{vmatrix} = \begin{vmatrix} -1.74 & 34D^2+150D \\ -0.162 & -32.17 \end{vmatrix}$$

$$= 5.508D^2 + 24.30D + 55.98 = \delta_{21}$$

$$\begin{vmatrix} -X_w & -(X_q D+g) \\ D-Z_w & -(Z_q+U)D \end{vmatrix} = \begin{vmatrix} -0.162 & -32.17 \\ D+3.95 & 115.5D \end{vmatrix}$$
$$= 13.46D + 127.1 = \delta_{31}$$

$$\begin{vmatrix} -(Z_q+U)D & -Z_u \\ k^2 D^2 - M_q D & -M_u \end{vmatrix} = \begin{vmatrix} 115.5D & 0.557 \\ 34D^2+150D & 0 \end{vmatrix}$$
$$= -18.94D^2 - 83.56D = \delta_{12}$$

$$\begin{vmatrix} D-X_u & -(X_q D+g) \\ -M_u & k^2_B D^2 - M_q \end{vmatrix} = \begin{vmatrix} D+0.128 & -32.17 \\ 0 & 34D^2+150D \end{vmatrix}$$

$$= 34D^3 + 154.3D^2 + 19.20D = \delta_{22}$$

$$\begin{vmatrix} -(X_q D+g) & D-X_u \\ -(Z_q+U)D & -Z_u \end{vmatrix} = \begin{vmatrix} -32.17 & D+0.128 \\ 115.5D & 0.557 \end{vmatrix}$$
$$= -115.5D^2 - 14.78D - 17.92 = \delta_{32}$$

$$\begin{vmatrix} -Z_u & D-Z_w \\ -M_u & -M_w \end{vmatrix} = \begin{vmatrix} -0.557 & D+3.95 \\ 0 & -1.74 \end{vmatrix}$$
$$= -0.9692 = \delta_{13}$$

$$\begin{vmatrix} -X_w & D-X_u \\ -M_w & -M_u \end{vmatrix} = \begin{vmatrix} -0.162 & D+0.128 \\ -1.74 & 0 \end{vmatrix}$$
$$= 1.74D + .2227 = \delta_{23}$$

$$\begin{vmatrix} D-X_u & -X_w \\ -Z_u & D-Z_w \end{vmatrix} = \begin{vmatrix} D+0.128 & -0.162 \\ 0.557 & D+3.95 \end{vmatrix}$$
$$= D^2 + 4.078D + .5957 = \delta_{33}$$

The value of the determinant Δ is

$$34D + 288.7D^3 + 833.0D^2 + 115.1D + 31.18 =$$
$$34(D^4 + 8.490D^3 + 24.50D^2 + 3.385D + 0.9170).$$

(The value of the determinant checks by three calculations.)

The roots of the equation

$$f(D)=D^4+8.49D^3+24.5D^2+3.385D+0.917=0 \tag{16}$$

determine the decrements and periods of the natural oscillations, and must be found. (Unfortunately these roots must be found with considerable accuracy, and the rough first approximations, such as are indicated by Bairstow, seem insufficient for our use.) Let it be assumed that one root is so large that it may be found approximately from

$$D^4+8.49D^3+24.5D^2=D^2+8.49D+24.5=0.$$

Then $D=-4.245\pm2.545i$.

If now r be an approximate solution of $f(D)=0$, a new approximation may be had by assuming $r+x$, with x small, as a root.

Then

$$x=-\frac{f(r)}{f'(r)}=-\frac{r^4+8.49r^3+24.5r+3.385r+0.917}{4r^3+25.47r^2+49r+3.385}$$

approximately. As $r^2+8.49r+24.5=0$, the fraction simplifies to

$$x=-\frac{3.385r+0.917}{23.08r+211.4}=.063+.107i,$$

if $r=-4.245-2.545i$. This root of $f(D)=0$ is therefore

$$D=-4.182\pm2.438i.$$

The factor of $f(D)$ corresponding to this pair of roots is

$$D^2+8.364D+23.43. \tag{17a}$$

Let the other factor be D^2+aD+b. Then $23.43b=0.917$ and $b=.03914$. Also, $8.364(.0391)+23.43a=3.385$ or $23.43a=3.058$ and $a=.1305$. Hence the second factor is

$$D^2+.1305D+.03914. \tag{17b}$$

As a check on the work we may multiply the two factors together; we find

$$(D^2+8.364D+23.43)\ (D^2+.1305D+.03914)=$$
$$D^4+8.494D^3+24.56D^2+3.385D+.9170.$$

We can find, merely by careful trial, better factors as

$$\begin{aligned}&(D^2+8.359D+23.37)\ (D^2+.1308D+.03924)=\\&D^4+8.490D+24.50D^2+3.385D+.9170.\end{aligned} \tag{18}$$

The definitive roots of $f(D)=\Delta=0$ may therefore be taken as

$$\begin{aligned}a&=-4.180-2.430i, & b&=-4.180+2.430i\\ c&=-.0654-.1870i, & d&=-.0654+.1870i\end{aligned} \tag{19}$$

Article 4.

INTEGRATION FOR HIGH SPEED.

The numerical equation for u is (see 14a):

$$\begin{aligned} &34\,(D^4+8.49\,D^3+24.5\,D^2+3.385\,D+0.917)\,u \\ &=(X_u\delta_{11}+Z_u\delta_{21})\,u_1+D\delta_{22}w_1+M_q\delta_{31}q_1 \\ &=-34\,(0.128\,D^3+1.160\,D^2+3.385\,D+0.917)\,u_1 \qquad (20a) \\ &+34\,D\,(0.162\,D^2+0.715\,D+1.647)\,w_1 \\ &-34\,(59.37\,D+560.6)\,q_1. \end{aligned}$$

The numerical equation for w is (see 14b):

$$\begin{aligned} &34\,(D^4+8.49\,D^3+24.5\,D^2+3.385\,D+0.917)\,w \\ &=(X_w\delta_{12}+Z_w\delta_{22}+M_w\delta_{32})\,w_1+D\delta_{12}u_1+M_q\delta_{32}q_1 \\ &=-34\,(3.95\,D^3+23.94\,D^2+3.385\,D+0.917)\,w_1 \qquad (20b) \\ &-34\,D^2\,(0.557\,D+2.458)\,u_1 \\ &+34\,(509.5\,D^2+65.21\,D+79.05)\,q_1. \end{aligned}$$

The numerical equation for θ is (see 14c):

$$\begin{aligned} &34\,(D^4+8.49\,D^3+24.5\,D^2+3.385\,D+0.917)\,\theta \\ &=M_q\delta_{33}q_1+D\delta_{13}u_1+D\delta_{23}w_1 \qquad (20c) \\ &=34\,(4.412\,D^2+17.99\,D+2.628)\,q_1 \\ &-34\,(0.02851)\,Du_1+34\,D(.05117\,D+.00655)\,w_1. \end{aligned}$$

The solutions are of the type:

$$\begin{aligned} u&=C_{11}e^{at}+C_{12}e^{bt}+C_{13}e^{ct}+C_{14}e^{dt}+I_u, \\ w&=C_{21}e^{at}+C_{22}e^{bt}+C_{23}e^{ct}+C_{24}e^{dt}+I_w, \qquad (21) \\ \theta&=C_{31}e^{at}+C_{32}e^{bt}+C_{33}e^{ct}+C_{34}e^{dt}+I_\theta, \end{aligned}$$

where a, b, c, d are the roots of the biquadratic (see 19), C_{ij} certain constants of integration, and I_u, I_w, I_θ a set of particular solutions of the equations. We shall determine I_u, I_w, I_θ in such a manner that they will not contain the functions e^{at}, etc.; we may therefore determine in advance the relations between the twelve C's. (This will debar us from using as gusts u_1, w_1, q_1, those which are of the form Ce^{at}, etc.; but this restriction is not important—such a damped gust tuned to the damping and period of the machine is highly improbable in nature.)

If we substitute u, w, θ in the equations (14), the particular solutions must cancel out among themselves (since they can not cancel terms of the form e^{at}) and leave

$$\begin{aligned} &(a-X_u)\,C_{11}e^{at}-X_wC_{21}e^{at}-(X_qa+g)\,C_{31}e^{at}+\text{similar terms}=0, \\ &-Z_uC_{11}e^{at}+(a-Z_w)\,C_{21}e^{at}-(Z_q+U)\,aC_{31}e^{at}+\ldots\ldots\ldots\ldots=0, \\ &-M_uC_{11}e^{at}-M_wC_{21}e^{at}+(k^2_BD^2-M_qD)\,C_{31}e^{at}+\ldots\ldots\ldots\ldots=0. \end{aligned}$$

These equations hold identically in t, and the coefficient of e^{at}, etc., in each must vanish. The three homogeneous equations in the three unknowns C_{11}, C_{21}, C_{31} (or the similar equations in C_{12}, C_{22}, C_{32}; C_{13}, C_{23}, C_{33}; C_{14}, C_{24}, C_{34}) are consistent because a (or b c, d) is a root of the determinant Δ, and the solutions are:

$$C_{11}:\ C_{21}:\ C_{31}=\begin{vmatrix}-X_w & -g\\ a-Z_w & -Ua\end{vmatrix}:\begin{vmatrix}-g & a-X_u\\ -Ua & -Z_u\end{vmatrix}:\begin{vmatrix}a-X_u & -X_w\\ -Z_u & a-Z_w\end{vmatrix},$$

with C_{12}: C_{22}: C_{32} determined by the same functions of b. In words: To obtain the ratios of the coefficients of e^{at} in u, v, w, substitute $D=a$ in the determinants δ_{31}, δ_{32}, δ_{33}. Or C_{12}: C_{21}: C_{31} as

$13.46a+127.1\ :\ -115.5a^2-14.78a-17.92\ :\ a^2+4.078a+.5957$
or C_{11}: C_{21}: $C_{31}=13.46a+127.1\ :\ 950.8a+2560\ :\ -4.281a-22.81$.
This gives C_{11}: C_{21}: C_{31} as

$70.8-32.7\,i:-1414-2310\,i:-4.92+10.40\,i$ or as

$$1:\ -4.04-34.52i:\ -.1132+.0946\,i.$$

The values of C_{12}: C_{22}: C_{32} are the conjugates

$$1:-4.04+34.5i:-.1132-.0946\,i.$$

To find C_{13}: C_{23}: C_{33} we must substitute $c=-.065-.187\,i$ in the same determinants. Then

C_{13}: C_{23}: $C_{33}=13.46c+127.1:.33c-13.39:3.947c+.5565$. This gives C_{13}: C_{23}: C_{33} as

$$126.2-2.516\,i:-13.37-.0623\,i:\ .2983-.7380\,i$$
or
$$1:-.1058-.002587\,i:.002478-.005799\,i.$$

The values of the conjugates are:

$$C_{14}:\ C_{24}:\ C_{34}=1:-.1058+.002587\,i:\ .002478+.005799\,i.$$

The general solutions of the equation of motion are:

$$u=C_{11}e^{at}+C_{12}e^{bt}+C_{13}e^{ct}+C_{14}e^{dt}+I_u, \tag{22a}$$
$$w=(-4.04-34.5\,i)C_{11}e^{at}+(-4.04+34.5\,i)C_{12}e^{bt} \\ +(-.1058-.002587\,i)C_{13}e^{ct}+(-.1058+.002587\,i)C_{14}e^{dt}+I_w, \tag{22b}$$
$$\theta=(-.1132+.0946\,i)C_{11}e^{at}+(-.1132-.0946\,i)C_{12}e^{bt} \\ +(.002478-.005799\,i)C_{13}e^{ct}+(.002478+.005799\,i)C_{14}e^{dt}+I_\theta. \tag{22c}$$

From these equations we see that the heavily damped short period oscillation (roots a, b) is about $34\frac{1}{2}$ times as strong in w as in u; whereas the mildly damped long period oscillation (roots c, d) is about $9\frac{1}{2}$ times as effective in u as in w. Moreover, the short period motions in u and w are about quartered; but the long period motions are in opposite phase. The amplitude of the short period motion in θ is about $\frac{1}{240}$ that of w; hence for each foot-second of short oscillation in w there is about $\frac{1}{4}°$ in θ. The amplitude of the long period motion in θ is about .006 of that in u; hence for each foot-second of long oscillation in u there is about $\frac{1}{3}°$ in θ. The damping of the short oscillation is so strong that the amplitude is reduced to about one-

ninetieth in one second where in the case of the long oscillation the reduction is only to about nine-tenths of its original value in one second; the relative amplitudes in the cases of u, w, θ are more important in the case of the long than in that of the short period oscillation because the latter is so quickly damped out that the swing may not get well started. However, the extreme magnitude of the short period oscillation in w as compared with u indicates the possibility of relatively violent accelerations in w; indeed, it is the short period oscillation which may account for initial difficulties whereas the long period oscillation accounts for the progressive troubles, due to gusts.

There remain to be determined the values of the constants C of integration from the initial conditions of uniform flight, i. e., $u=w=\theta=q=0$. Let the particular solutions have the initial values I_{u0}, I_{w0}, $I_{\theta 0}$. Then

$$
\begin{aligned}
&0=C_{11}+C_{12}+C_{13}+C_{14}+I_{u0},\\
&0=(-4.04-34.5i)\,C_{11}+(-4.04+34.5\,i)\,C_{12}\\
&\quad+(-.1058-.002587\,i)\,C_{13}+(-.1058+.002587\,i)\,C_{14}+I_{w0},\\
&0=(-.1132+.0946\,i)\,C_{11}+(-.1132-.0946\,i)\,C_{12}\\
&\quad+(.002478-.005799\,i)\,C_{13}+(.002478+.005799\,i)\,C_{14}+I_{\theta 0},\\
&0=(-.1132+.0946\,i)aC_{11}+(-.1132-.0946\,i)bC_{12}\\
&\quad+(.002478-.005799\,i)cC_{13}+(.002478+.005799\,i)dC_{14}+I'_{\theta 0},\\
&\text{or } 0=(.703-.205\,i)\,C_{11}+(.703+.205\,i)\,C_{12}+(-.001246-.000084\,i)\,C_{13}\\
&\qquad\qquad+(-.001246+.000084\,i)\,C_{14}+I'_{\theta 0}.
\end{aligned}
$$

The values of C_{11}, C_{12} and C_{13}, C_{14} are conjugate imaginaries; hence $C_{11}+C_{12}=A$, $C_{13}+C_{14}=B$, $i(C_{12}-C_{11})=C$, $i(C_{14}-C_{13})=D$ are real. The equations may therefore be written

$$
\begin{aligned}
&0=A+B+I_{u0}\\
&0=-4.04\,A+34.5\,C-.1058\,B+.002587\,D+I_{w0}\\
&0=-.132\,A-.0946\,C+.002478\,B+.005799\,D+I_{\theta 0}\\
&0=.703\,A+.205\,C-.001246\,B+.000084\,D+I'_{\theta 0}.
\end{aligned}
$$

The values for A, B, C, D are (as found by determinants and checked by substitution):

$$
\begin{aligned}
A&=-.0008856\,I_{u0}+.008198\,I_{w0}+.01621\,I_{\theta 0}-1.372\,I'_{\theta 0},\\
C&=-.003196\,I_{u0}-.02803\,I_{w0}+.01476\,I_{\theta 0}-.1543\,I'_{\theta 0},\\
B&=-(1-.0008856)I_{u0}-.008198\,I_{w0}-.01621\,I_{\theta 0}+1.372\,I'_{\theta 0},\\
D&=.3577\,I_{u0}-.2940\,I_{w0}-172.0\,I_{\theta 0}-29.89\,I'_{\theta 0}.
\end{aligned}
\tag{23}
$$

The solutions (22) of the equations of motion of the aeroplane involve imaginary numbers from which they may be freed by using A, B, C, D in place of C_{11}, C_{12}, C_{13}, C_{14}. The equations then become

$$
\begin{aligned}
u=e^{-4.18t}\,&(A\cos 2.43t+C\sin 2.43t]\\
&+e^{-.0654t}\,(B\cos .187t+D\sin .187t)+I_u,
\end{aligned}
$$

$$
\begin{aligned}
w=e^{-4.18t}\,&[(34.5\,C-4.04\,A)\cos 2.43t\\
&-(34.5\,A+4.04\,C)\sin 2.43t]\\
&+e^{-.0654t}[(.002587\,D-.1058\,B)\cos .187t\\
&\quad-(.002587\,B+.1058\,D)\sin .187t]+I_w,
\end{aligned}
$$

$$\theta = e^{-4.18t}[-(.1132\,A + .0946\,C)\cos 2.43t + (.0946\,A - .1132\,C)\sin 2.43t] + e^{-.0654t}[(.00278\,B + .005799\,D)\cos .187t + (.002478\,D - .005799\,B)\sin .187t] + I_\theta.$$

These formulas enable us to study any particular gust we desire.

It is merely necessary to find the particular solutions, then the constants A, B, C, D. We shall reduce the coefficients in the parentheses. Then

$$u = e^{-4.18t}(A\cos 2.43t + C\sin 2.43t) + e^{-.0654t}(B\cos .187t + D\sin .187t) + I_u, \qquad (24a)$$

$$w = e^{-4.18t}(A'\cos 2.43t + C'\sin 2.43t) + e^{-.0654t}(B'\cos .187t + D'\sin .187t) + I_w, \qquad (24b)$$

$$\theta = e^{-4.18t}(A''\cos 2.43t + C''\sin 2.43t) + e^{-.0654t}(B''\cos .187t + D''\sin .187t) + I_\theta, \qquad (24c)$$

where

$$\begin{aligned} A' &= -.1066\,I_{u0} - 1.0001\,I_{w0} + .4436\,I_{\theta_0} + .220\,I'_{\theta_0}, \\ C' &= .04346\,I_{u0} - .1696\,I_{w0} - .6190\,I_{\theta_0} + 47.93\,I'_{\theta_0}, \\ B' &= .1066\,I_{u0} + .000107\,I_{w0} - .4436\,I_{\theta_0} - .220\,I'_{\theta_0}, \\ D' &= -.03523\,I_{u0} + .03112\,I_{w0} + 18.20\,I_{\theta_0} + 3.158\,I'_{\theta_0}, \end{aligned} \qquad (25)$$

$$\begin{aligned} A'' &= +.0004024\,I_{u0} + .001724\,I_{w0} - .003231\,I_{\theta_0} + .1698\,I'_{\theta_0}, \\ C'' &= +.0002778\,I_{u0} - .003947\,I_{w0} - .000136\,I_{\theta_0} - .1123\,I'_{\theta_0}, \\ B'' &= -.0004024\,I_{u0} - .001724\,I_{w0} - .99676\,I_{\theta_0} - .1698\,I'_{\theta_0}, \\ D'' &= .006683\,I_{u0} - .000681\,I_{w0} - .4261\,I_{\theta_0} - .08201\,I'_{\theta_0}. \end{aligned} \qquad (26)$$

In any particular case the calculation of the coefficients in (24) from (23), (25), (26) is likely to be relatively simple because there are so many terms that for that case may be negligible.

Article 5.

SOME SPECIAL GUSTS.

If we wish to represent a gust which, starting from the condition of still air, increases to a certain intensity J we may use the function

$$J(1 - e^{-rt}). \qquad (24)$$

The value of r determines the sharpness of the gust. If $r=1$, the gust has reached about two-thirds of its value in one second; if $r=5$, the gust has reached two-thirds of its value in one-fifth of a second; if $r=\frac{1}{5}$, the two-thirds intensity is reached in 5 seconds. We may perhaps regard $r=1$ as giving a moderately sharp gust, $r=5$ as giving a very sharp, and $r=\frac{1}{5}$ as giving a tolerably mild gust. The function (24) has the advantage of being in such form that the determination of the particular integrals is easy. (See Wilson's Advanced Calculus.)

CASE 1. *Head-on gust—mild.* $u_1 = J\,(1-\epsilon^{-.2t})$.
In equations (20) we let $u_1 = J\,(1-\epsilon^{-.2t})$, $w_1 = q_1 = 0$. Then

$$\begin{aligned} I_u &= -J\,(1-.247\,\epsilon^{-.2t}), & I_{u0} &= -.753J, \\ I_w &= .082J\,\epsilon^{-.2t}, & I_{w0} &= -.082J, \\ I_\theta &= -.00495J\,\epsilon^{-.2t}, & I'_{\theta 0} &= -0049J, \\ I'_\theta &= .00099J\,\epsilon^{-.2t}, & I'_{\theta 0} &= .00099J. \end{aligned}$$

(N. B.—The total increase J of the wind occurs everywhere as a factor and may be omitted—the results then are for an increase of 1 foot-second.)

$$u = J\epsilon^{-.0054t}(.622\cos .187t + .630\sin .187t) - J(1-.247\epsilon^{-.2t}),$$

$$w = J\epsilon^{-4.18t}(-.004\cos 2.43t + .003\sin 2.43t) - J\epsilon^{-.0054t}(.078\cos .187t + .059\sin .187t) + .082J\epsilon^{-.2t},$$

$$\theta = J\epsilon^{-.0054t}(.00495\cos .187t - .0031\sin .187t) - .00495J\epsilon^{-.2t}.$$

It appears from these equations that the effect of a mild head-on gust of magnitude J is as follows: (1) The machine takes up an easy slowly damped oscillation in u of amplitude about 89 per cent of J; after the oscillation dies out the machine is making a speed J less relative to the ground and hence the original speed relative to the wind. (2) There is a rapidly damped oscillation in w of rather small magnitude and a slowly damped one of about 10 per cent of J, the final condition being that of horizontal flight. (3) There is a slow oscillation in pitch of about .0058 J radians or about .32 $J°$. If the magnitude J is great, the pitching becomes so marked that the approximate method of solution can no longer be considered valid—a gust of 20 foot-seconds causing a pitch of some 6°. As the period is long (about one-half minute) the pilot should have ample time to correct the trouble before it produces serious consequences.

The result of a tail-on gust is the opposite of that of the head-on gust and therefore need not be treated separately. For the head-on gust J is negative; for a rear gust, positive.

To calculate the stresses on the machine or operator caused by the gust we have merely to find the accelerations du/dt and dw/dt of which the first is (approximately)—

$$du/dt = J\epsilon^{-.0054t}(.08\cos .187t - .16\sin .187t) - .05J\epsilon^{-.2t}.$$

This acceleration reaches a maximum of something of the order of $J/10$; and if J should be 20 foot-seconds, the acceleration would be only about 2, or 6 per cent of g—not a large amount. The acceleration dw/dt is likewise small. (N. B.—The initial accelerations du/dt and dw/dt should vanish, because the gust starts from zero. That the initial values are not exactly zero in the above formulas is due to the roughness of the final calculations for u and w.)

The path of the machine varies from the horizontal by the amount

$$z = \int_0^t (w + 115.5\theta)\,dt$$

which accounts for the effect of the vertical velocity and of the climbing in the path. The result is (roughly)

$$z = J\int_o^t e^{-.0654t}(.5 \cos .187t - .4 \sin .187t)dt - .5e^{-.2t}dt,$$

$$z = J[e^{-.0654t}(\cos .187t + 3 \sin .187t) + 2.5e^{-.2t} - 3.5].$$

The motion is oscillatory approaching as a limit $z = -3.5\ J$. The machine will rise 70 feet when the gust is 20 foot-seconds head-on.

CASE 2. *Up gust—mild.* $w_1 = J(1 - e^{-.2t})$.

$$I_u = .305\ Je^{-.2t}, \qquad I_{u0} = .305\ J,$$

$$I_w = J(1 - 1.012e^{-.2t}), \qquad I_{w0} = -.012\ J,$$

$$I_\theta = .000737\ Je^{-.2t}, \qquad I_{\theta 0} = .000737\ J,$$

$$I'_\theta = -.000147\ Je^{-.2t}, \qquad I'_{\theta 0} = -.000147\ J.$$

$$u = Je^{-.0654t}(-.305 \cos .187t - .0108 \sin .187t) + .305\ Je^{-.2t},$$

$$w = Je^{-4.18t}(-.02 \cos 2.43t + .026 \sin 2.43t) + Je^{-.0654t}(.032 \cos .187t + .002 \sin .187t) + J(1 - 1.012e^{-.2t}),$$

$$\theta = Je^{-.0654t}(.0008 \cos 187t + .0017 \sin .187t) + .00074e^{-.2t}).$$

The effect of the up gust is to set up a small long oscillation in u of magnitude about 0.3 J, a very small oscillation in w, and a long oscillation of intensity .0018 J radians or .11 $J°$ in θ. The comparative effects on the velocity and angle in the case of head-on and up gusts show that the up gust is only about one-third as effective as the head-on gust. The accelerations in the case of the up gust are all small.

To find the displacement in a vertical direction we integrate as before.

$$z = \int_0^t (w + 115.5\theta)dt.$$

It is scarcely necessary to trouble with the trigonometric terms partly because the motion is less pronounced than in Case 1, partly because there is here the secular term Jt, which will carry the machine up with the gust and will be the chief effect after the lapse of a short time.

A down gust is in every way the opposite of an up gust and need not be separately treated.

CASE 3. *Rotary gust—mild.* $q_1 = J(1 - e^{-.2t})$.

$$I_u = -J(610.6 - 475.5e^{-.2t}), \qquad I_{u0} = -135.1\ J.$$

$$I_w = J(86.21 - 74.87e^{-.2t}), \qquad I_{w0} = 11.34\ J.$$

$$I_\theta = J(2.865 + .691e^{-.2t}), \qquad I_{\theta 0} = 3.556\ J.$$

$$I_{\dot\theta} = -.138\ Je^{-.2t}, \qquad I'_{\theta_0} = -.138\ J.$$

$$\begin{aligned} I_u = {} & Je^{-4.18t}(.46 \cos 2.43t + .1875 \sin 2.43t) \\ & + Je^{-.0654t}(134.7 \cos .187t - 659 \sin .187t) \\ & - J(610.6 - 475.5e^{-.2t}), \end{aligned}$$

$$\begin{aligned} I_w = {} & Je^{-4.18t}(4.61 \cos 2.43t - 16.82 \sin 2.43t) \\ & + Je^{-.0654t}(-15.95 \cos .187t + 70.08 \sin .187t) \\ & + J(86.21 - 74.87e^{-.2t}), \end{aligned}$$

$$\begin{aligned} I_\theta = {} & Je^{-4.18t}(-.0698 \cos 2.43t + .0223 \sin 2.43t) \\ & + Je^{-.0654t}(-3.487 \cos .187t - 2.414 \sin .187t) \\ & + J(2.865 + .691\ e^{-.2t}). \end{aligned}$$

The effect of the rotary gust is a long oscillation in u (the short one is negligible) of magnitude about 670 J, a short oscillation in w of about 17 J and a long one of about 71 J, a long oscillation in θ of about 4.1 J. The comparison with former cases may be made by supposing first that the oscillation in u may reach some 20 foot-seconds. Then $J = 1/33 = .03$. The amplitude of the oscillation in θ is then some 0.12 radians, which is an amount comparable with the 6° of Case 1. To get an idea of what $J = .03$ means, we may note that if a gust of 20 foot-seconds is due to a whirl of the air as a solid body with $q_1 = .03$, the radius of the whirl is 660 feet. We may therefore say that the effect of a whirl of radius 660 generating velocity of 20 foot-seconds is of itself about equal to that of a head-on velocity of that amount. If, however, a machine ran into such a whirl, it would experience both the effect of the whirl and of the linear velocity generated by it and would be disturbed considerably more than if it had encountered a pure head-on gust. We may therefore say that if the head-on gust arises from a whirl of materially less than 660-foot radius, the effect of the whirl is quite considerably larger than that due to a straight head-on gust of equal magnitude.

The conditions after enough time has elapsed to allow the exponential term to become small is

$$I_u = -610.6\ J. \quad I_w = 86.2\ J. \quad I_\theta = 2.865\ J.$$

It is therefore seen that the machine takes up the head-on velocity, acquires a small upward velocity, and is inclined at an angle 2.865J radians to the horizontal, these effects being due exclusively to the rotary motion of the air. The path in space could be obtained by integration, but (like the effects previously mentioned) would not be the true path if the rotary motion were accompanied by horizontal or vertical linear gusts. It seems therefore scarcely worth while to find the path.

The value that I attach to this theory of rotary gusts does not arise so much from the fact that such gusts seem nowhere to have been treated as from the revelation of the powerful effects of such gusts. When a machine is flying low it must expect to meet air which has been set in rotation by the friction of the wind against the ground, against buildings, or against trees. It seems certain that very material angular velocities might be set up and that these might (owing to their short radius) induce only moderate linear gusts. In such cases, if they can arise as assumed, the machine

might behave very much worse than could be foreseen when nothing is known of rotary gusts. It is not unlikely, however, that rotary gusts would be very irregular themselves and that, before the machine could feel the full effects of one, the gust might have disappeared. In the same way rotation could be generated at the interface between dark and light regions of air—indeed any sharp relative motion of the air is likely to contain rotation.

CASE 4. *Head-on gust—moderate.* $u_1 = J(1-e^{-t})$.

$$I_u = -J(1+.09876e^{-t}), \qquad I_{uo} = -1.09876\ J,$$

$$I_w = .1307\ Je^{-t}, \qquad I_{wo} = .1307\ J,$$

$$I_\theta = -.00196\ Je^{-t}, \qquad I_{\theta_0} = -.00196\ J,$$

$$I'_\theta = +.00196\ Je^{-t}, \qquad I'_{\theta_0} = +.00196\ J.$$

$$\begin{aligned} u = {} & Je^{-4.18t}(-.000676 \cos 2.43t - .000486 \sin 2.43t \\ & + Je^{-.0654t}(1.09944 \cos .187t - .1528 \sin .187t) \\ & - J\ (1+.09876e^{-t}), \end{aligned}$$

$$\begin{aligned} w = {} & Je^{-4.18t}(-.01405 \cos 2.43t + .02528 \sin 2.43t) \\ & + Je^{-.0654t}(-.1159 \cos .187t + .01493 \sin .187t) \\ & + .1307 Je^{-t}, \end{aligned}$$

$$\begin{aligned} \theta = {} & Je^{-4.18t}(.0001207 \cos 2.43t - .00000895 \sin 2.43t) \\ & + Je^{-.0654t}(.001838 \cos .187t - .006755 \sin .187t) \\ & - .00196\ Je^{-t}. \end{aligned}$$

The short oscillation in u is negligible not only in regard to its magnitude but even as far as accelerations are concerned. Then

$$du/dt = Je^{-.0654t}(-.1 \cos .187t + .21 \sin .187t) + .1Je^{-t}.$$

This is at most about .25 J, or 5 foot-seconds[2] if $J=20$. The short oscillation in w is considerably smaller than the long, but when the coefficients -4.18 and 2.43 are brought in by differentiating to find dw/dt, whereas $-.0654$ and .187 are brought in by the long oscillation, it appears that the short oscillation is effective in determining the acceleration. Thus

$$\begin{aligned} dw/dt = {} & Je^{-4.18t}(.12 \cos 2.43t - .07 \sin 2.43t) \\ & + Je^{-.0654t}(.01 \cos .187) - .13\ Je^{-t}. \end{aligned}$$

The amount of this acceleration is at most about $J/12$, one-third that in u; the effect, however, is produced very quickly, in the first half second.

In integrating to find the path in a vertical plane we may neglect the short oscillation, because in this case we divide by -4.18 and 2.43, whereas for the long oscillation we divide by $-.0654$ and .187. Then

$$z = \int_0^t (w + 115.5\theta)dt$$

$$= J\int_0^t [e^{-.0654t}(.106 \cos .187t - .765 \sin .187t) - .095e^{-t}]dt$$

$$= Je^{-.0654t}(2.3 \sin .187t + 3.5 \cos 1.87t) + .095\ Je^{-t} - 3.6\ J.$$

The final condition is a rise of $-3.6\ J$, an amount which agrees with that in the case of the mild gust (Case 1) in as far as the rough calculation of that case permits us to judge.

CASE 5. *Up gust—moderate.* $w_1 = J(1-e^{-t})$.

$$I_u = .0773\ Je^{-t}, \qquad I_{u0} = .0773\ J,$$
$$I_w = -J\ (1 - 1.205\ e^{-t}), \qquad I_{w0} = .205\ J,$$
$$I_\theta = -.003069\ Je^{-t}, \qquad I_{\theta_0} = -.003069\ J,$$
$$I'_\theta = .003069\ Je^{-t}, \qquad I'_{\theta_0} = .003069\ J.$$

$$u = Je^{-4.12t}(-.002641 \cos 2.43t - .00651 \sin 2.43t) + Je^{-.0654t}(= .07466 \cos .187t + .4034 \sin .187t) + .0773\ Je^{-t},$$

$$w = Je^{-4.12t}(-.2139 \cos 2.43t + .1174 \sin 2.43t) + Je^{-.0654t}(.008943 \cos .187t - .02337 \sin .187t) - J(1 - 1.205e^{-t}),$$

$$\theta = Je^{-4.12t}(.0009148 \cos 2.43t + .000487 \sin 2.43t) + Je^{-.0654t}(+.002154 \cos .187t - .001432 \sin .187t) - .003069\ Je^{-t}.$$

The short oscillation is negligible in u as far as concerns u itself. In calculating the acceleration du/dt the short oscillation is not negligible relative to the long; but the acceleration is small any way. The effect of an up gust J on u is about one-third the effect of an equal head-on gust (see Case 2).

The short oscillation is the main thing in w—its amplitude is about $J/4$, whereas the amplitude of the long oscillation is about $J/40$, or one-tenth as much. The acceleration dw/dt may therefore be calculated exclusively from the short oscillation; it is

$$dw/dt = Je^{-4.12t}(1.2 \cos 2.43t) - J\ (1 - e^{-t}).$$

This means values approximately as follows:

$$t = 0,\ \tfrac{1}{8},\ \tfrac{1}{4},\ \tfrac{1}{2},\ \tfrac{3}{4},$$
$$acc. = 0, -.35\ J, -.6\ J, -.7\ J, -.6\ J.$$

If J should be 20 foot-seconds, the maximum acceleration would be about $g/2$, even a gust of 10 foot-seconds would produce an acceleration of $g/4$. Such accelerations coming upon the pilot in one-half a second might considerably surprise and disturb him. An addition of 25 to 50 per cent in the apparent weight of the machine could hardly strain it to an appreciable extent in view of the large factor of safety used in the design. (N. B.—For an up gust J is negative. For a down gust the operator would lose 25 to 50 per cent of his weight.)

The path of the machine in space is not of great importance in this case. The chief feature is the general drift of the machine with the current.

CASE 6. *Rotary gust—moderate.* $q_1 = J\ (1 - e^{-t})$.

As we know so little of the rotation in the atmosphere and as nothing particular of interest seems to be indicated for this case over and above what was found in Case 3, we shall not carry out the calculations.

CASE 7. *Head-on gust—sharp.* $u_1 = J\ (1 - e^{-5t})$.

$$\begin{aligned} I_u &= -J(1 + .01872\ e^{-5t}), & I_{uo} &= -1.01872\ J, \\ I_w &= -.05102\ Je^{-5t}, & I_{wo} &= -\ \ .05102\ J, \\ I_\theta &= -.0008896\ Je^{-5t}, & I_{\theta_0} &= -.0008896\ J, \\ I'_\theta &= 004448\ Je^{-5t}, & I'_{\theta_0} &= .004448\ J. \end{aligned}$$

$$\begin{aligned} u = {} & Je^{-4.18t}(-.005632 \cos 2.43t + .003986 \sin 2.43t), \\ & + Je^{-.0654t}(1.02435 \cos .187t - .3294 \sin .187t), \\ & - J(1 + .01872\ e^{-5t}), \\ w = {} & Je^{-4.18t}(.1603 \cos 2.43t + .1782 \sin 2.43t), \\ & + Je^{-.0654t}(-.1093 \cos .187t + .0322 \sin .187t), \\ & - .05102\ Je^{-5t}, \\ \theta = {} & Je^{-4.18t}(.00026 \cos 2.43t - .000984 \sin 2.43t), \\ & + Je^{-.0654t}(.000628 \cos .187t - .006755 \sin .187t). \\ & - .0008896\ Je^{-5t}. \end{aligned}$$

Here again the short oscillation in u is insignificant. The long oscillation as in Case 4 has an amplitude a little in excess of J. The acceleration du/dt is small of the order $J/5$. The reason that a sharp head gust does not give a large value to du/dt is probably because the gust can blow through the machine; the acceleration is therefore not large except at the loops of the slow oscillation.

The short-period oscillation in w has now become stronger than the long oscillation and the acceleration dw/dt is mostly due to it and may be written

$$dw/dt = Je^{-4.18t}(-.25 \cos 2.43t - 1.13 \sin 2.43t) + .25\ Je^{-5t}.$$

The value of the acceleration never gets large because it is damped out before the sine term gets effective—perhaps $-0.4\ J$ would be about its maximum value. A sharp head-on gust is therefore about half as effective as a moderate up gust of the same intensity. Since up gusts are perhaps not likely to be as intense as head-on gusts, we might hazard a guess that sharp head-on gusts would inconvenience the pilot about as much as moderate up gusts.

The most important terms in the path in space are

$$z = Je^{-.0654t}(1.2 \sin .187t + 3.5 \cos .187t) - 3.5\ J.$$

The total rise is again $-3.5\ J$.

CASE 8. *Up gust—sharp.* $w_1 = J(1 - e^{-5t})$.

$$\begin{aligned} I_u &= .06621\ Je^{-5t}, & I_{uo} &= .06621\ J, \\ I_w &= -J(1 - .5605\ e^{-5t}), & I_{wo} &= -.4395\ J, \\ I_\theta &= -.00778\ Je^{-5t}, & I_{\theta_0} &= -.00778\ J, \\ I'_{\theta_0} &= .0389\ Je^{-5t}, & I'_{\theta_0} &= .0389\ J. \end{aligned}$$

$$\begin{aligned} u = {} & Je^{-4.18t}(-.05714 \cos 2.43t + .006 \sin 2.43t) \\ & + Je^{-.0654t}(-.00907 \cos .187t + .3285 \sin .187t) \\ & + .06621\ Je^{-5t}, \end{aligned}$$

$$\begin{aligned} w = {} & Je^{-4.18t}(.4378 \cos 2.43t + 1.947 \sin 2.43t) \\ & + Je^{-.0654t}(.00181 \cos .187t - .03474 \sin .187t) \\ & - J(1 - .5605\ e^{-5t}), \end{aligned}$$

$$\begin{aligned}\theta = Je^{-.418t}&(.0059 \cos 2.43t - .0122 \sin 2.43t)\\ &+ Je^{-.0654t}(.001883 \cos .187t + .0008667 \sin .187t)\\ &- .00778\, Je^{-5t}.\end{aligned}$$

The oscillation in u is of long period, and the acceleration in u is small. The oscillation in w has a short-period term of great importance at the start, but except for this there is very little oscillation in w. The acceleration is

$$dw/dt = Je^{-4.18t}(2.9 \cos 2.43t - 9.2 \sin 2.43t) - 2.8\, Je^{-5t}.$$

(N. B.—The value of dw/dt when $t=0$ should be 0 instead of $J/10$. The failure to check seems due to multiplication of errors, which is unavoidable. The accuracy of the work in Case 8 and Case 5 appears reduced to two figures.) The acceleration is now very serious indeed; it is about $-9.2\, Je^{-4.18t} \sin 2.43t$, as the other two terms come near canceling. The maximum value occurs when $t=.217$, a little over one-fifth of a second, as is then about $-1.85\, J$. If J should be as large as -18 foot-seconds, the acceleration would equal $g=32$. Clearly such a sharp gust if it existed would be very dangerous from the sudden forces it would bring into play. As the machine, however, would travel only about 24 feet during one-fifth second, it is reasonable to doubt whether in so short a distance so large a change in vertical air velocity could occur.

The path in space is found to be approximately

$$z = -1.2\, Je^{-4.18t} \cos 2.43t + 1.1\, Je^{-.0654t} \cos .187t - .1\, Je^{-5t} + .2\, J - Jt.$$

The final effect is the general drift with the gust, less a lag of $J/5$.

Article 6.

THE CONSTRAINED AEROPLANE.

If an aeroplane is constrained to remain always horizontal by mechanism which does not otherwise alter the machine or its dynamical properties, the equations of motion in a gust may be found from our previous equations by setting $\theta = q = 0$. Then

$$\begin{aligned}(D - X_u)\, u - X_w w &= X_u u_1 + X_w w_1 + X_q q_1,\\ -Z_u u + (D - Z_w)\, w &= Z_u u_1 + Z_w w_1 + Z_q q_1,\\ -M_u u - M_w w \quad &= M_u u_1 + M_w w_1 + M_q q_1 + F,\end{aligned}$$

where F is the effective force due to the constraint and is assumed to affect moments only, not components of horizontal or vertical force. The last equation merely determines F.

With the numerical data we find for high speed

$$\begin{aligned}(D. + 128)u - .162w \quad &= -.128u_1 + .162w_1,\\ .557u + (D + 3.95)w &= -.557u_1 - 3.95w_1,\\ F &= -.174(w + w_1) + 150q_1.\end{aligned}$$

The natural motion of the machine when slightly disturbed in steady air is found from

$$\Delta' = \begin{vmatrix} D+.128 & -.162 \\ .557 & D+3.95 \end{vmatrix} = D^2 + 4.078D + .598 = 0.$$

The roots are

$$D = -2.039 \pm 1.887 = -3.926 \text{ or } -0.152.$$

We thus find the first result: The machine, when disturbed, does not execute a double damped oscillation, but has an aperiodic motion of the form

$$C\ e^{-3.93t} + C_2\ e^{-0.15t}.$$

The two damping factors -3.93 and -0.15 lie between the values -4.18 and $-.0654$ previously found.

The unconstrained machine was stable for the speeds 79, 51, and 47 mile-hours; unstable for 45.2 mile-hours and lower speeds. If we take the data for 47 mile-hours and use them for the constrained motion, we find

$$\Delta'' = \begin{vmatrix} D+.151 & .075 \\ +.936 & D+1.46 \end{vmatrix} = D^2 + 1.61\ D + .150 = 0,$$

of which the roots are -1.51 and $+.10$. The natural motion of the machine is therefore of the form

$$C_2\ e^{-1.51t} + C_2\ e^{.10t}.$$

The second factor indicates instability; the motion due to it increases instead of subsides and reaches 2.78 times its original value in 10 seconds. We thus find the second result: The machine, when constrained, becomes unstable at a higher speed than when free—it is to this extent a more dangerous machine.

We shall now return to the case of high speed and compute the effect of certain gusts on the constrained machine for comparison with the effect of the same gusts on the free machine. The general solutions are

$$\begin{aligned}
u &= -.0426\ C_1\ e^{-3.93t} + C_2\ e^{-.15t} + I_u,\\
w &= C_1\ e^{-3.93t} - .147\ C_2\ e^{-.15t} + I_w.\\
C_1 &= -.148\ I_{uo} - 1.006\ I_{wo},\\
C_2 &= -1.006\ I_{uo} - .0429\ I_{wo}.\\
\Delta' u &= -(.128\ D + .598)\ u_1 + .162\ Dw_1,\\
\Delta' w &= -(3.95\ D + .598)\ w_1 - .557\ Du_1.
\end{aligned}$$

Case 1. *Head-on gust—mild.* $u_1 = J\ (1 - e^{-.2t})$.

$$\begin{aligned}
I_u &= -J\ (1 + 3.20\ e^{-.2t}), & I_{uo} &= -4.20\ J,\\
I_w &= .622\ Je^{-.2t}, & I_{wo} &= .622\ J.\\
u &= 4.19\ Je^{-.15t}, - J\ (1 + 3.19\ e^{-.2t}), & &\\
w &= -.62\ Je^{-.15t} + .62\ Je^{-.2t}. & &
\end{aligned}$$

The machine takes up the gust as before, of course. There is no oscillation. There is practically no acceleration in either u or w. The path in space is

$$z = J\,(4.1\,e^{-.15t} - 3.1\,e^{-.3t}) - J.$$

The total rise is only $-J$. In every way the motion in this case is easier in the constrained than in the free aeroplane.

CASE 2. *Up gust—mild.* $w_1 = J(1 - e^{-.3t})$.

$$I_u = -.186\,Je^{-.3t}, \qquad I_{u0} = -.186\,J,$$
$$I_w = -J(1 - 1.079\,e^{-.3t}), \qquad I_{w0} = .079\,J.$$
$$u = .186\,Je^{-.15t} - .186\,Je^{-.3t},$$
$$w = -.052\,Je^{-2.99t} - .027\,Je^{-.15t} - J(1 - 1.079\,e^{-.3t}).$$

The motion is again exceedingly moderate in all respects.

CASE 3. *Rotary gusts.* These can have no effect except upon the constraining moment F.

CASE 4. *Head-on gust—moderate.* $u_1 = J(1 - e^{-t})$.

$$I_u = -J(1 + .1895\,e^{-t}). \qquad I_{u0} = -.1895\,J,$$
$$I_w = .2246\,Je^{-t}, \qquad I_{w0} = .2246\,J.$$
$$u = .002\,Je^{-2.99t} + 1.187\,Je^{-.15t} - J(1 + .189\,e^{-t}),$$
$$w = -.05\,Je^{-2.99t} - .174\,Je^{-.15t} + .224\,Je^{-t}.$$
$$du/dt = -.008\,Je^{-2.99t} - .180\,Je^{-.15t} + 1.89\,Je^{-t}.$$
$$dw/dt = .197\,Je^{-2.99t} + .027\,Je^{-.15t} - .224\,Je^{-t}.$$
$$z = 1.16\,Je^{-.15t} - .22\,Je^{-t} - .94\,J.$$

The motion is again decidedly moderate.

CASE 5. *Up gust—moderate.* $w_1 = J(1 - e^{-t})$.

$$I_u = -.0653\,Je^{-t}, \qquad I_{u0} = -.0653\,J,$$
$$I_w = -J(1 - 1.350\,e^{-t}), \qquad I_{w0} = .350\,J.$$
$$u = .0144\,Je^{-2.99t} + .0507\,e^{-.15t} - .0653\,Je^{-t},$$
$$w = -.343\,Je^{-2.99t} - .007\,e^{-.15t} - J(1 - 1.350\,e^{-t}).$$
$$dw/dt = +1.35\,Je^{-2.99} - 1.35\,Je^{-t}.$$

The motion is easy except for the acceleration in w, which has a maximum when $t = .46$ and is then equal to about $-.62\,J$. If the gust should have an intensity of 10 foot-seconds the maximum acceleration would be about $g/5$.

CASE 6. *Head-on gust—sharp.* $u_1 = J(1 - e^{-5t})$.

$$I_u = -J(1 + .00795e^{-5}), \qquad I_{u0} = -1.008\,J,$$
$$I_w = -.5275\,Je^{-5t}, \qquad I_{w0} = -.5275\,J.$$
$$u = -.029\,Je^{-2.99t} + 1.037\,Je^{-.15t} - J\,(1 + .008\,e^{-5t}).$$
$$w = .680\,Je^{-2.99t} - .152\,Je^{-.15t} - .528\,Je^{-5t}.$$
$$dw/dt = -2.67\,Je^{-2.99t} + .02\,Je^{-.15t} + 2.64\,Je^{-5t}.$$
$$z = -.173\,Je^{-2.99t} + Je^{-.15t} + .103\,Je^{-5t} - .93\,J.$$

The motion, including acceleration, is moderate.

CASE 7. *Up gust—sharp.* $w_1 = J(1-e^{-5t})$.

$$I_u = .153\, Je^{-5t}, \qquad I_{u0} = .153\, J,$$

$$I_w = -J(1+3.628e^{-5t}), \qquad I_{w0} = -4.628\, J,$$

$$u = -.197\, Je^{-3.93t} + .044\, Je^{-.15t} + .153\, Je^{-5t},$$

$$w = 4.634\, Je^{-3.93t} - .006\, Je^{-.15t} - J(1+3.628\, e^{-5t}).$$

$$dw/dt = -18.2\, Je^{-3.93t} + 18.2\, Je^{-5t},$$

$$z = -1.18\, Je^{-3.93t} + .04\, Je^{-.15t} + .73\, Je^{-5t} + .41\, J - Jt.$$

The acceleration dw/dt has a maximum when $t=5/11$ when it is $1.44\, J$. This is somewhat serious if J is 10 foot-seconds.

We may now calculate roughly the moment F necessary to produce the constraint.

$$F = -.174(w+w_1) + 150q_1.$$

The last term is effective only when the machine encounters rotating air and will be neglected here.

CASE 1. $F = .11\, J(e^{-.15t} - e^{-.2t})$.

CASE 2. $F = J(.009\, e^{-3.93t} + .005\, e^{-.15t} - .014\, e^{-.2t})$.

CASE 4. $F = J(.009\, e^{-3.93t} + .030\, e^{-.15t} - .039\, e^{-t})$.

CASE 5. $F = J(.06\, e^{-3.93t} + .0012\, e^{-.15t} - .0612\, e^{-t})$.

CASE 6. $F = J(-.119\, e^{-3.93t} + .0266\, e^{-.15t} + .0924\, e^{-5t})$.

CASE 7. $F = .811\, J(-e^{-3.93t} + e^{-5t})$.

SUMMARY.

I have indicated the general method, based on the theory of small oscillations, whereby the equations of motion of a stable aeroplane, whether free or constrained to fly without pitch, whether in steady or gusty air, may be completely integrated in such form that, after a certain amount of preliminary calculation, the effects upon the motion of a large number of different gusts may be determined with relative ease. So far as I am aware, no actual method of integration nor any quantitative results of such an integration has previously been published with the exception of the descriptive popular lecture of Glazebrook cited above. I have carried through the actual determination of the effects of gusts in the following cases:

Head-on gusts rising from 0 to J feet per second with various degrees of sharpness.

Up gust of the same type.

Rotary gusts of the same type.

Rear gusts and down gusts are included by merely changing the sign of J. For convenience, it has been assumed that the machine is in still air except for the gustiness; as a matter of fact gusts are usually superposed upon a general steady wind of other than zero

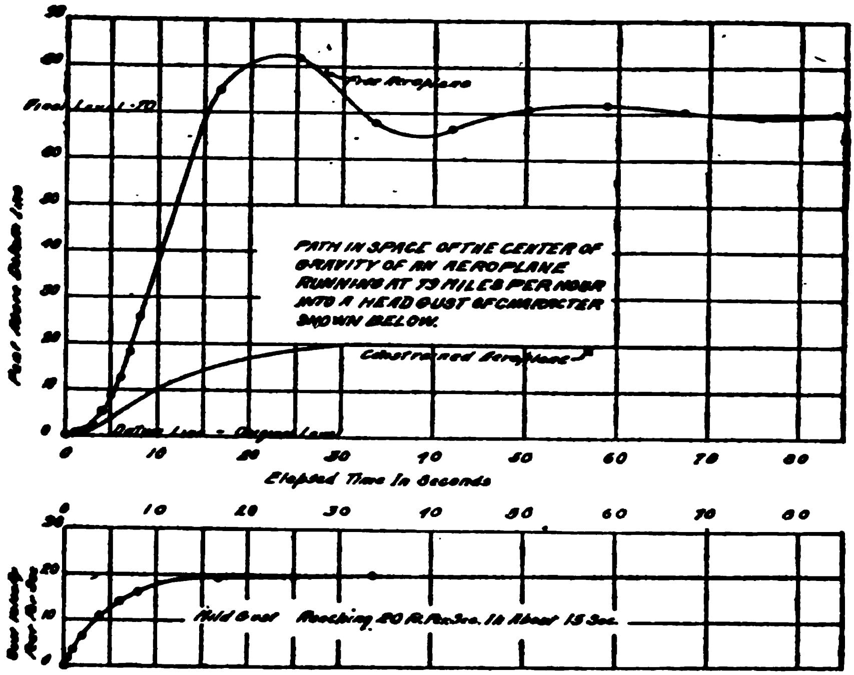
average velocity; but the conditions of flight in still air and in steady air are nearly identical, the only difference being that in the equations of motion the resistance derivatives are calculated from the relative wind, whereas U is the actual velocity over the ground.

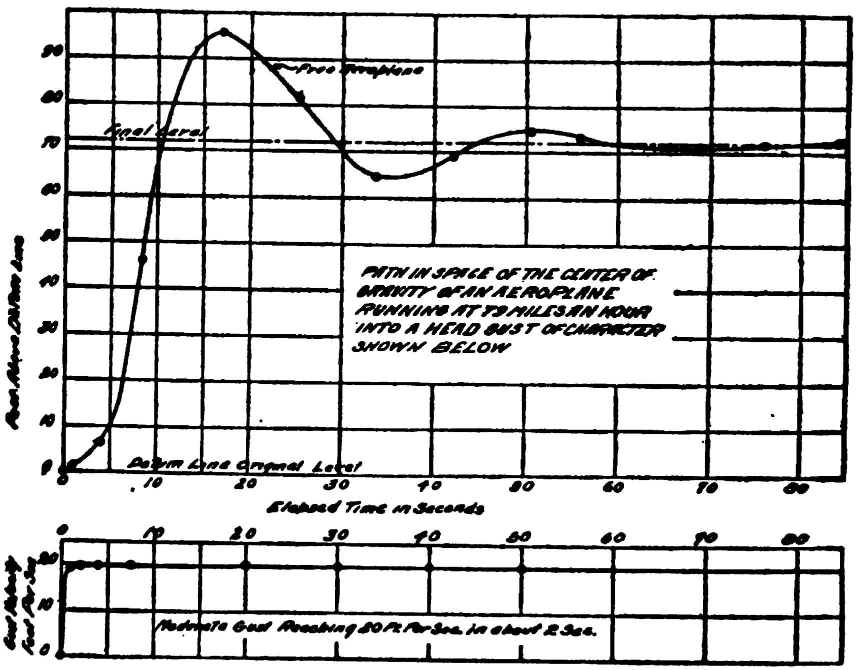
It has been found that a stable machine, with controls untouched, running into a head gust of various sharpness and of total intensity J foot-second will swoop up, with some oscillation of no serious character, to a new level about 3.5 J feet higher than its previous level. The constrained machine will rise without oscillation to a new level only J feet, or a trifle less, higher than before. The path in a vertical plane is indicated in the diagrams drawn for me by Mr. T. H. Huff. The accellerations arising in the motion are not serious for either the machine or the pilot. It has been found further that a rotary gust may have considerable effect—though in the absence of data as to the intensity and regularity of rotation in the air no definite results can be formulated. Furthermore we find that up gusts operate chiefly in lifting the machine, whether free or constrained, with the gust. The path in space is given in the diagram. There is here in the case of sharp gusts a considerable momentary acceleration in the vertical which may reach a magnitude of about 1.5 J foot-seconds.[3] This would not seriously stress the machine, which is designed to stand accelerations of 6 g to 8 g in maneuvering, but owing to its sudden and unexpected appearance this acceleration might incommode the pilot—it is indeed the familiar phenomenon of a "bump."

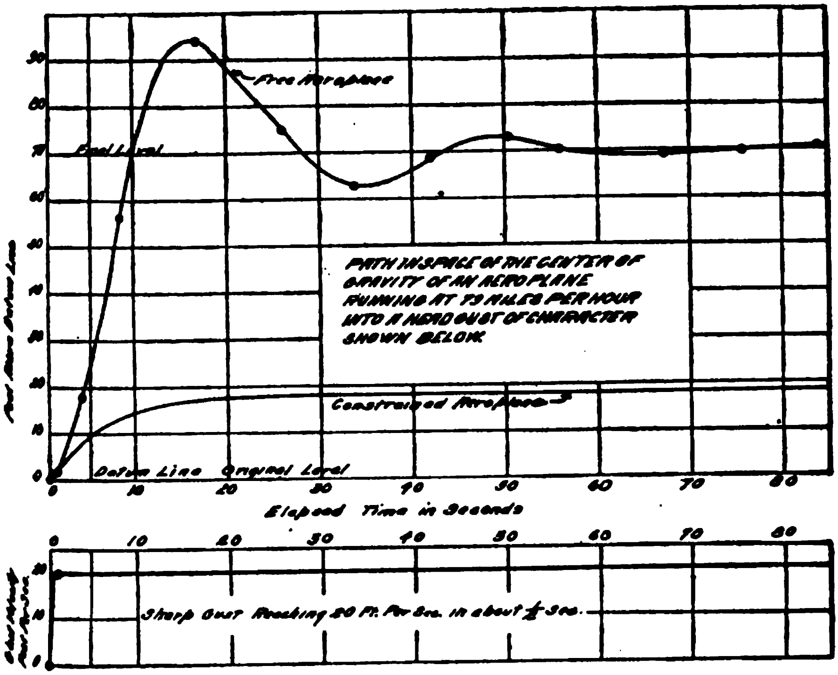
It follows, therefore, that the introduction of the constraint, whether by gyroscopic or other means, serves only to eliminate the natural oscillation in pitch and to diminish, in the case of the head or rear gusts only, the final change of level. As a rear gust of 20 foot-seconds is found to drop the uncontrolled machine by more than 80 feet in 15 seconds, flight at low altitudes is more dangerous in the unconstrained than in the constrained machine. However, the elapsed time is sufficiently great to enable the pilot to check the dip by a suitable movement of his elevator.

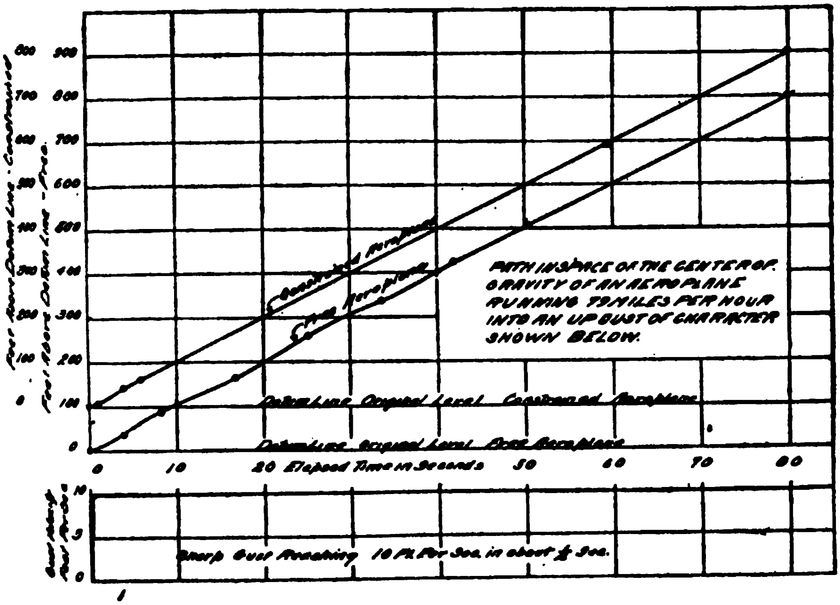
To offset any advantages derived from the constraint, we find that this particular machine, when constrained, becomes unstable at a speed between 47 and 51 mile-hours, whereas the free machine remains stable down to a speed between 45 and 47 mile-hours.

Massachusetts Institute of Technology,
Boston, Mass., October 7, 1915.


Free Aeroplane
PATH IN SPACE OF THE CENTER OF GRAVITY OF AN AEROPLANE RUNNING AT 73 MILES PER HOUR INTO A HEAD GUST OF CHARACTER SHOWN BELOW.
Constrained Aeroplane
Datum Line = Original Level
Elapsed Time In Seconds
Mild Gust Reaching 20 Ft. Per Sec. In About 15 Sec.


Free Aeroplane
Final Level
PATH IN SPACE OF THE CENTER OF GRAVITY OF AN AEROPLANE RUNNING AT 73 MILES AN HOUR INTO A HEAD GUST OF CHARACTER SHOWN BELOW
Datum Line Original Level
Elapsed Time in Seconds
Moderate Gust Reaching 20 Ft. Per Sec. in about 2 Sec.


Free Aeroplane
Final Level
PATH IN SPACE OF THE CENTER OF GRAVITY OF AN AEROPLANE RUNNING AT 73 MILES PER HOUR INTO A HEAD GUST OF CHARACTER SHOWN BELOW.
Constrained Aeroplane
Datum Line Original Level
Elapsed Time in Seconds
Sharp Gust Reaching 20 Ft. Per Sec. in about ½ Sec.


Constrained Aeroplane
Free Aeroplane
PATH IN SPACE OF THE CENTER OF GRAVITY OF AN AEROPLANE RUNNING 73 MILES PER HOUR INTO AN UP GUST OF CHARACTER SHOWN BELOW.
Datum Line Original Level Constrained Aeroplane
Datum Line Original Level Free Aeroplane
Elapsed Time in Seconds
Sharp Gust Reaching 10 Ft. Per Sec. in about ½ Sec.

REPORT No. 2.

IN TWO PARTS.

INVESTIGATION OF PITOT TUBES.

BY THE UNITED STATES BUREAU OF STANDARDS.

Part 1.—THE PITOT TUBE AND OTHER ANEMOMETERS FOR AEROPLANES.

By W. H. HERSCHEL,

Part 2.—THE THEORY OF THE PITOT AND VENTURI TUBES.

By E. BUCKINGHAM.

CONTENTS OF REPORT NO. 2.

REPORT NO. 2.

PART 1.

THE PITOT TUBE AND OTHER ANEMOMETERS FOR AEROPLANES.

By W. H. Herschel.

1. INTRODUCTION.

The air pressures on the wings of an aeroplane, and therefore the sustaining power of the wings and the stresses to which the whole structure is subject, depend on the speed of the machine relative to the air through which it is moving. The measurement of this speed—particularly near the lower limit where the sustaining power becomes deficient and there is danger of stalling, or at very high speeds where any movement of the controls may give rise to dangerously large stresses—is evidently a matter of importance, and the use of a reliable anemometer or speedometer is highly desirable. The aim of the following paper is to describe the principles of operation of some of the instruments which have been devised or used for this purpose and to discuss their characteristics, so far as it can be done from a general point of view or on the basis of available information, without undertaking new experimental investigations.

Since the Pitot tube is the instrument which has been most commonly used in the United States and Great Britain as a speedometer for aeroplanes, it will be treated first and somewhat more fully than the others.

2. GENERAL REMARKS ON THE PITOT TUBE.

The speed-measuring device known, after its inventor,[1] as the Pitot tube contains two essential elements. The first is the dynamic opening, or mouth of the impact tube, which points directly against the current of liquid or gas of which the speed is to be measured, and receives the impact of the current. The second is the static opening for obtaining the so-called static pressure of the moving fluid, i. e., the pressure which would be indicated by a pressure gauge moving with the current and not subject to impact. To avoid the influence of impact, the static opening points at right angles to the dynamic opening. If the two openings are connected to the two sides of a differential pressure gauge, the gauge shows a head which depends on

[1] Origin and Theory of the Pitot Tube, H. E. Guy Engineering News, June 5, 1913, p. 1172.

the speed and density of the current in which the tube is placed, and which may be used as a measure of the speed of the fluid past the Pitot tube.

If the fluid is a liquid and the two openings are connected to a U gauge containing the same liquid, the gauge shows a head h and the usual formula for computing the speed S is

$$S = C\sqrt{2gh} \tag{1}$$

in which g is the acceleration of gravity and C is the "coefficient" or "constant" of the given instrument. If the head h is read on a gauge containing a liquid of density d while the density of the fluid (either gas or liquid) in which the Pitot tube is immersed is ρ, equation (1) takes the modified form:

$$S = C\sqrt{2g\frac{d}{\rho}h} \tag{2}$$

According to the elementary theory as usually given, C should be exactly 1, and in practice it is in fact in the neighborhood of unity, when the instrument is properly designed and used with suitable precautions.

As regards design, it may be said that numerous recent investigations have shown that almost any sort of dynamic opening is satisfactory, but that the static opening must be designed with great care in order that the coefficient C may be set equal to unity without involving any sensible error in the result of using equation (2). Rowse,[1] for example, has made an extensive comparison of various forms of Pitot tube, which confirms previous results obtained by White,[2] Taylor,[3] Treat,[4] and others. With the most satisfactory tube tested, the experimental error in S was found to be not over 0.2 per cent. whether the static pressure was taken from a piezometer ring,[5] or from the static opening of the tube as supplied by the maker. The standard of comparison was a Thomas electric meter, which was assumed to give correct readings.[6]

It may therefore be concluded that by proper construction the Pitot tube can be made to have a coefficient so near unity that for all ordinary purposes the equation

$$S \doteq \sqrt{2g\frac{d}{\rho}h} \tag{3}$$

may be regarded as sensibly accurate.

3. ERRORS WHICH MAY OCCUR IN THE INTERPRETATION OF PITOT-TUBE READINGS.

The simple theory which leads to equation (3) assumes that the tube is always pointed exactly against the current and that the observed head, h, is due to the instantaneous value of the speed S.

[1] W. C. Rowse, Trans. A. S. M. E., 1913, p. 633.
[2] W. M. White, Journal Association of Engineering Societies, August, 1901.
[3] D. W. Taylor, Society of Naval Architects and Marine Engineers, November, 1905.
[4] Chas. H. Treat, Trans. A. S. M. E., 1912, p. 1019.
[5] The piezometer was simply an air-tight annular space about the pipe, connected with the interior of the pipe by six small holes.
[6] For accuracy of Thomas meter see C. C. Thomas, Journal Franklin Institute, vol. 172, p. 411, and Proceedings Am. Gas Inst., vol. 7, 1912, p. 339. For more recent experimental verifications of equation (2) without use of the Thomas meter, see F. H. Bramwell, Report of British Committee on Aeronautics, 1912–1913, p. 35, and Wm. Cramp, Manchester Memoirs, vol. 58, part 2, sec. 7.

These assumptions are never exactly fulfilled in ordinary practice and accordingly exact results may not be obtained, even when no fault is to be found with the instrument itself.

In the first place, it is impossible to read the gauge instantaneously; furthermore, there is always a time lag between the openings and the gauge. Accordingly, even when the current does not change in direction, if its speed varies rapidly all that can be observed is the mean value of h over a certain time interval, and this value does not correspond to the arithmetical mean value of S over the same interval, even if the interval is long compared with the time lag, as has been shown experimentally by Rateau.[1]

Disregarding the time lag, the value of S computed by equation (3) will be the root-mean-square speed, which is always larger than the arithmetical mean speed. Hence if, for example, the Pitot tube is being used to determine the discharge through a steam main feeding a reciprocating engine, the computed discharge will be greater than the true discharge. This error is not likely to be very large. If, for instance, the speed varies sinusoidally with time from 0.5 to 1.5 times its arithmetical mean value, the linear speed computed by equation (3) will be 1.0607 times the arithmetical mean speed which determines the total flow, or a trifle over 6 per cent. too large.

A second cause of error is rapid variability in direction of the current, which makes it impossible to keep the tube pointed correctly even when mounted on a vane. If, as is usually the case, it is desired to measure merely the component velocity in a fixed direction, the eddies which almost always exist may introduce a considerable error when this component velocity is computed by equation (3). If the variations of direction are small, the error is due almost entirely to the effect on the static opening and not to change of the direction of impact on the dynamic opening.[2]

This source of error is much reduced in the Dines tube, a form of Pitot tube in which the static opening consists of a number of round holes or longitudinal slits in a hollow cylinder placed with its axis perpendicular to the direction of the impact tube and to the plane in which the variations of direction are expected to occur. When this instrument is employed as an anemometer, its principal use, the cylinder is of course vertical.

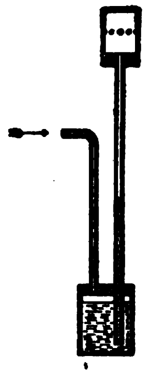
The heads given by the Dines tube are sensibly independent of errors in direction up to about 20° on each side of the mean. To offset this advantage, the instrument is somewhat less sensitive than the ordinary Pitot tube, the coefficient C being greater than 1. Furthermore, each tube must be calibrated separately, and it is not even certain that the coefficient is strictly constant for each tube. Data by Dines[3] show a constant coefficient $C=1.53$. Jones and Booth[4] find values from 1.20 to 1.70 for different tubes. Zahm[5] finds values from 1.42 to 1.50, depending on the speed.

It has sometimes been doubted whether the coefficient C of a given Pitot tube was dependent solely on the relative speed of the fluid and the tube, the suggestion being that a tube standardized by mov-

[1] Annales des Mines, 1898, p. 341.
[2] L. F. Moody, Proceedings Engineers' Society of Western Pennsylvania, May, 1914.
[3] Quarterly Journal, Royal Meteorological Society, vol. 18, 1892.
[4] Aeronautical Journal, July, 1913, p. 195.
[5] Physical Review, 1903, p. 410.

ing through a quiescent medium, as with a whirling arm in air, may not give correct results when used to determine the velocity of a fluid past a fixed point. It is difficult to see how the Pitot tube can respond to anything but velocity relative to itself. At all events, experiments by Fry and Tyndall[1] have shown that while there was some apparent disagreement at speeds below 11 miles per hour (17.7 kilometers) where the experimental errors were large, for higher speeds, up to 36 miles per hour (58 kilometers) both methods of standardization gave the same result.

Which method of standardization should be adopted—motion of the tube or motion of the fluid—may, nevertheless, depend on the purpose for which the instrument is intended. It is impossible in practice to set up an artificial current of fluid which shall have a high speed and not be turbulent and full of eddies; and the only conditions to which equations (1) and (2) refer are, in strictness, those of steady stream-line flow or steady motion of the tube in a quiescent fluid. If



Dines anemometer

the tube is to be used in a very turbulent medium, as, for example, in measuring the discharge from a fan, it should be standardized in a stream of fluid in which the turbulence is about the same as it will be under the working conditions. It might very well happen that a given tube when tested on the whirling arm or by moving through still water gave a coefficient $C=1$, while if the tube were tested in a turbulent current some other value of C was obtained. If the tube were to be used to measure the average speed of a similarly turbulent current, this second coefficient should be used and not the value $C=1$.

Apparent errors and inconsistencies in the results obtained by equations (1) and (2) have probably been due in part to disregarding the foregoing obvious considerations.

4. WORKING FORMULAS FOR PERFECT PITOT TUBES.

It will be convenient to collect here, for reference, certain practical working forms of equation (3) for the perfect or ideal Pitot tube, that is, for a tube having the coefficient C equal to unity. If the tube does not satisfy this condition, whether on account of its design or from

[1] J. D. Fry and A. M. Tyndall, Philosophical Magazine (6), vol. 21, p. 348 1911.

the necessary circumstances of practical use, the value of C must be determined by experiment, and the values of S given by the following equations are then to be multiplied by the observed values of C.

We start by inserting the value $g=32.17$ ft./sec.^{2} or 9.81 m./sec.^{2} in the general equation (3), viz:

$$S=\sqrt{2gh\frac{d}{\rho}} \qquad (3)$$

in which $S=$ the speed of the current,
$h=$ the head on the differential gauge,
$d=$ the density of the liquid in the gauge,
$\rho=$ the density of the current.

From this we obtain special equations for practical use.

(*A*) *Any two fluids.*—d and ρ may have any values but are to be measured in the same units. The value of S is given by the equation

$$S=X\sqrt{h\frac{d}{\rho}} \qquad (4)$$

with the values of X shown in Table 1 for various methods of expressing S and h.

TABLE 1.—*Values of X for equation (4).*

h measured in—	S measured in—	X.
Inches of liquid of density d	Ft./sec	2.316
	Ft./min	138.9
	Mile/hour	1.579
Mm. of liquid of density d	M./sec	.1411
	M./min	8.404
	Km./hour	.5043

(*B*) *Any moving fluid, gauge liquid water.*—The value of S is given by the equation

$$S=Y\sqrt{\frac{h}{\rho}} \qquad (5)$$

with the values of Y shown in Table 2.

TABLE 2.—*Values of Y for equation (5).*

h measured in—	ρ measured in—	S measured in—	Y.
Inches of water at 68° F.=20° C	Lbs./ft.^{3}	Ft./sec	18.28
		Ft./min	1097
		Mile/hour	12.46
Mm. of water at 68° F.=20° C.	Kgm./m.^{3}	M./sec	4.426
		M./min	265.5
		Km./hour	15.93

When the Pitot tube is to be used in air, the air density ρ for use in equations (4) and (5) may be found as follows:

Let B = the barometric pressure.

Let t = the temperature of the air.

Let P = the pressure of saturated steam at $t°$, from the steam tables.

Let H = the relative humidity.

Then in English units, if B and P are in inches of mercury and t in degrees F.,

$$\rho = 1.327 \frac{B - 0.376PH}{460 + t} \text{ lbs./ft.}^3 \tag{6}$$

or in metric units, if B and P are in millimeters of mercury and t in degrees C.,

$$\rho = 0.464 \frac{B - 0.376PH}{273 + t} \text{ kgm./m.}^3 \tag{6a}$$

All the numerical data given in this section are accurate enough to permit of computing the speed to within 0.1 per cent. Actual values computed from equation (6) may be found from Table 7, section 13. The calculations required by equation (6) may be avoided by the use of diagrams given by Rowse[1] and Taylor.[2] Hinz[3] gives a diagram showing the gas constant of moist air, which may be used in place of equation (6a).

5. ERRORS OF THE PITOT TUBE AT VERY HIGH SPEEDS.

The theory of the action of the Pitot tube, as given in Part 2 of this paper, shows that the equations given in the preceding sections must be expected to require a correction if the observed pressure difference is enough to compress the fluid sensibly. This will never occur when liquids are in question, though when the instrument is used for measuring the speed of a gas the correction required to allow for compressibility might become sensible at high speeds. But for the highest speeds attained by aeroplanes, say 130 miles per hour, the correction computed from the theory is less than 0.5 per cent., an amount which is altogether negligible in comparison either with the errors of observation or with the uncertainties of the theory itself, which is far from convincingly rigorous.

6. GENERAL REMARKS ON RESISTANCE ANEMOMETERS.

When a fixed obstruction is placed in a current of fluid, it experiences a force in the direction of flow which depends upon and may be used as a measure of the speed of the current. The force depends on the relative motion and is the same, at the same relative speed, when the fluid is at rest and the body moves through it, the force then appearing as a resistance to the motion. It is the resultant of forces exerted on the elements of the surface of the body (a) normally by the pressure, which varies from point to point; and (b) tangentially

[1] Loc. cit., p. 690.
[2] Loc. cit., p. 39, and plates 33 and 34.
[3] Adolf Hinz, Thermodynamische Grundlagen der Kolben und Turbokompressoren, p. 42.

by skin friction of the fluid moving along the surface. Since we are now interested only in devices which may be used as anemometers, we may as well, for the future, say "air" instead of fluid, and "wind" instead of current.

As regards the pressure, there is always, on the windward or upstream side, a region of increased pressure, i. e., of excess above the general static pressure of the air; while on the leeward or downstream side there is a deficiency. In the Pitot tube, the obstruction consists of the impact tube with its open mouth at the upstream end. This receives the excess pressure and transmits it to the gauge. The instrument deals solely with the excess pressure on the upstream side, of an obstruction of particularly simple form, the drag due to skin friction and the suction on the downstream side having no effect on the reading of what we have called a perfect Pitot tube.

The next simplest case is that of a thin flat plate of regular outline set normal to the wind. The skin friction forces balance one another and the whole normal force on the plate is the surface integral of the excess of pressure on the front, over that on the back. If the plate is mounted so that the force of the wind on it can be measured, it constitutes a "pressure-plate anemometer."

Various devices which are in practical use may be regarded as intermediate between the Pitot tube and the pressure plate anemometer. Among these are the Dines tube (see p. 82), the "Stauscheibe," and the Pneumometer. The Stauscheibe is a metal disk about 1 cm. in diameter with holes in the centers of its two faces from which the pressures are led to the two arms of the U gauge, through the disk and through the support by which the disk is held prependicular to the current. The Pneumometer differs from the Stauscheibe only in details of construction. For both these instruments the coefficient of equation (1) has the value 0.854, the observed pressure difference being influenced by the suction at the downstream face as well as by the impact pressure on the upstream face.[1]

In the case of pressure plate anemometers, it is usually the total force acting on the obstruction in the wind that is measured, rather than a manometric pressure, although Stanton [2] used a diaphragm and air pressure to transmit the force acting on a plate to a manometer 50 feet away.

If the solid obstruction is anything else than a thin flat plate normal to the wind, skin friction as well as pressure contributes to the resultant force; and if the body is not symmetrical about an axis parallel to the wind, the resultant force will not in general be parallel to the wind, but the body will receive a side thrust in addition to the resistance in the direction of the wind, as, for example, when the wing of an aeroplane has both lift and drift. Any body mounted so that the force on it can be measured, provides a means of measuring the speed of the wind and may be used as an anemometer; but if the body is to be held in a fixed orientation with respect to the wind, it is evidently simplest, mechanically, to avoid side thrust by making the body symmetrical about the wind direction, preferably a figure of revolution about that axis. The resistance offered to the wind by a symmetrical body of given maximum section normal to the wind

[1] Rowse, loc. cit., p. 677 and 684. A. Gramberg, Technische Messungen, third edition, 1914, p. 99. Cramp, loc. cit., p. 14.
[2] T. E. Stanton, Collected Researches, National Physical Laboratory, Vol. V, 1909, p. 169.

depends greatly on its shape, being less for a sphere than for a flat plate normal to the wind, and still less for a somewhat elongated spindle-shaped body.

Whatever the shape of the body may be, unless it is a sphere its resistance to a given wind depends on its presentation, and by a suitable choice of shape this variation of the force with the orientation may be made quite large. The operation of the Robinson, or cup anemometer, depends on the fact that the resistance of a hemispherical cup is greatest when the concave side is pointed to windward, so that a wind blowing in the plane of rotation of the cups always produces a torque. In the so-called "bridled" form of this anemometer, the torque is measured statically and the instrument is then merely a rather complicated form of pressure-plate anemometer. In the ordinary form of the instrument, in which the cups are allowed to revolve freely, the speed of the wind is measured indirectly by observing the speed of rotation, the action of the wind on the cups being then still more complicated.

From the fact that the pressure recorded by the Pitot tube is proportional to the square of the speed, it might be surmised that the total force observed with a pressure-plate or other static resistance anemometer would probably also be nearly proportional to the square of the speed; and this is confirmed by experiment. The analogy between these anemometers and the Pitot tube is a very close one, the Pitot tube being in principle only a particularly simple kind of resistance anemometer.

We have next to speak somewhat more in detail of some special types of resistance anemometer.

7. THE WIND RESISTANCE OF FLAT PLATES.

The resistance of a flat plate normal to a wind of velocity S is nearly proportional to S^2 and this relation is sometimes represented by writing

$$P = KS^2 \tag{7}$$

in which P is the force per unit area of the plate. The coefficient K is approximately proportional to the density of the air, but it varies with the size and shape of the plate. The independence of Pitot tube readings of the size and nature of the dynamic opening would lead us to expect that the pressure at the center of the front of the plate would be independent of the size and shape of the plate, and Stanton's[1] experiments confirm this expectation. But the suction on the back depends on size as well as speed, thus accounting for the variability of K and showing that P is only a fictitious pressure with no physical significance.

We shall confine our attention to square and round plates, for which the laws of the distribution of pressure are more simple than for very oblong rectangles.[2] When giving numerical values in "English units" pressure will be in pounds per square foot and speeds

[1] Loc. cit., p. 192.
[2] G. Finzi and N. Soldati, Engineering, Mar. 31, 1905, p. 397.

in miles per hour, while in "Metric units" pressure will be in kilograms per square meter and speeds in meters per second.

A. *Square plates.*—According to Eiffel [1] the value of the coefficient K of equation (7) in English units varies from 0.00266 for plates 4 inches square to $K=0.00326$ for plates 40 inches square or larger. The temperature and pressure of the air during the tests are not given. The corresponding metric values are 0.065 and 0.08. Bairstow and Booth [2] after analyzing the available data give the equation

$$F=0.00126\ (S\ l)^2+0.0000007\ (S\ l)^3$$

in which F is the total force in pounds, S is the speed in feet per second, and l is the length of side in feet. The equation refers to air at 760 mm. and 15° C. or 59° F. If S is measured in miles per hour the equation becomes

$$F=0.00271(Sl)^2+0.0000022\ (Sl)^3$$

and if put into the form (7), for the sake of comparison with Eiffel's results, it may be written

$$P=0.00271(1+0.0008\ Sl)S^2$$

the coefficient K depending on both S and l.

B. *Circular disks.*—For a circular disk 30 centimeters, or 11.8 inches, in diameter, Eiffel gives the value $K=0.00276$ English, or 0.0675 metric. Stanton [3] found the values $K=0.0027$ English (0.066 metric) by using a 2-inch disk. On the whole, Eiffel's results seem preferable, because the size of disk used by him is more nearly the desirable size for an anemometer.

As regards the relative importance of the front and back of the plate, it may be noted that in a wind of 10 meters per second or 22.4 miles per hour, Eiffel found that the front of his 12-inch disk accounted for 72 per cent of the whole resistance. Zahm [4] has pointed out that if a plate be surrounded by a sufficiently broad guard ring there will be no suction on the back, while the pressure on the front will be uniform and the same as indicated by a Pitot tube at the same speed.

Table 3 shows the force on a 12-inch disk for different wind velocities, the total resultant force being calculated from Eiffel's value of $K=0.00276$ English (0.0675 metric), and from Bairstow and Booth's formula for square plates, assuming, as some but not all experimenters have found, that the average pressure would be the same for a circular plate with a diameter equal to l, as for a square of side l.

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[1] G. Eiffel, The Resistance of the Air, p. 35.
[2] Report, British Advisory Committee for Aeronautics, 1910-11, p. 21.
[3] T. E. Stanton, Proceedings Inst. C. E., Vol. CLVI, 1903-4, part 2, p. 78.
[4] A. F. Zahm, Journal Franklin Institute, vol. 173, January-June, 1912, p. 266.

TABLE 3.—*Wind forces in pounds on a 12-inch disk.*

Wind speed S miles per hour.	Force in pounds according to Eiffel.	Force in pounds according to Bairstow and Booth.
30	1.94	1.97
40	3.47	3.50
50	5.40	5.53
60	7.80	8.00
70	10.60	11.01
80	13.88	14.48
90	17.55	18.48

TABLE 3A.—*Wind forces in kilograms on a 30-centimeter disk.*

Wind speed S kilometers per hour.	Force in kilograms according to Eiffel.	Force in kilograms according to Bairstow and Booth.
48.3	0.86	0.87
64.4	1.53	1.55
80.4	2.38	2.44
96.5	3.44	3.53
112.8	4.68	4.87
128.8	6.13	6.39
145.0	7.75	8.15

8. RESISTANCE OF SPHERES AND HEMISPHERES.

Next to thin plates and hemispherical cups the sphere has been most frequently employed in static resistance anemometers as the obstruction opposed to the wind. In addition to the fact that a sphere is symmetrical about all diameters, so that the indications of a sphere anemometer may be made independent of changes in wind direction, the sphere has the further advantage of simplicity of form so that it may readily be duplicated. A disadvantage of the sphere, as compared with thin plates, is the lower value of the coefficient K of equation (7).

According to W. H. Dines, as quoted by Lanchester,[1] K has a value of 0.00154 English for a sphere 6 inches in diameter, or 0.0378 metric for one 153 millimeters in diameter. Dines's tests were made with a velocity of 21 miles an hour (34 kilometers). Eiffel[2] gives K as 0.00045 (0.011 metric) and explains the difference between his value and that of 0.00112 (0.0275 metric) found at Göttingen, as follows: K decreases with an increase of velocity until a certain critical velocity is reached, after which K remains nearly constant at 0.00045 for the three spheres experimented upon. This critical velocity was found to be about 27 miles an hour for a 6-inch sphere, 16 miles for a 10-inch sphere, and 9 miles for a 13-inch sphere (12,

[1] F. W. Lanchester, Aerodynamics, p. 25.
[2] La Technique Aeronautique, 1913, p. 146.

7, and 4 meters per second, respectively, for the 16, 24, and 33 centimeter spheres). The high value of the Göttingen coefficient is, according to Eiffel, due to the fact that velocities of over 23 miles an hour (36 kilometers) can not be obtained at that laboratory. It will be noted that even for a 6-inch sphere the critical velocity is well below the lowest flying speeds used in practice.

Table 4 shows values of K for hemispherical cups, according to Dines.

TABLE 4.—*Values of K in equation (7) for hemispherical cups.*

	English.	Metric.	English.	Metric.	English.	Metric.
	Diameter of cup.					
	2½ in.	64mm.	5in.	127mm.	9in.	229mm.
Cup facing wind..............	0.00597	0.146	0.00386	0.095	0.00402	0.099
Cup with back to wind........	.00239	.059	.00168	.041	.00138	.034

Since Dines used only the one speed of 21 miles an hour, there is a doubt whether his values would hold for higher speeds. It appears that with a cup there would be little if any reduction in diameter as compared with a plate giving an equal force, though the cup would have the advantage of greater strength for a given force and weight. The difference in the force acting on the cup in its two positions, which is the driving force of the Robinson anemometer, is clearly indicated by the table.

9. PRACTICAL FORMS OF RESISTANCE ANEMOMETER.

Maxim [1] used a pressure plate anemometer consisting of a disk with a spring resistance. His arrangement had the advantage of fairly uniform graduations of the scale, the spring acting indirectly, with variable leverage on the pressure plate.

In the pressure-plate anemometer of Dines [2] the variable resistance is furnished by a float partly immersed in water, the pressure on the plate being equal to the weight of a volume of water equal to that of the part of the float raised above the water level.

The 1914 catalogue of Aera, Paris, shows a pressure plate anemometer which is merely a speed indicator. It is supplied with three disks, so that it may be set for any speed between 50 and 75 miles an hour (80 and 120 kilometers). The pointer will then show whether the actual speed is above or below the normal. Aera also make an anemometer using a sphere, in the form of a pendulum. This instrument reads only to 45 miles an hour (72 kilometers) and has graduations coming closer together at higher speeds. It would be very inaccurate without some means for holding it vertical.

The Davis Lyall air speed indicator, made by John Davis & Son, of Derby, England, is a bridled anemometer of the screw type which should be held with its back to the wind, though the manufacturers

[1] H. Maxim, Natural and Artificial Flight, p. 70.
[2] Quarterly Journal, Royal Meteorological Society, vol. 18, 1892, p. 167.

do not provide it with an air vane to do this automatically. This defect is remedied in the Aera bridled anemometer. Concerning the Davis Lyall instrument, it is stated:

To avoid undue oscillation of the pointer a damper is provided—either magnetic or air. Such a damper is rendered necessary in measuring velocities in a natural wind which varies within wide limits.

When it is desired to investigate the gusty character of natural winds, the sensitiveness of a bridled anemometer becomes an advantage. Concerning a bridled anemometer consisting of five hemispherical cups attached to a vertical spindle by short arms, Stanton[1] says that this instrument is more sensitive to momentary gusts than any of the other recording instruments in common use.

10. THE ANEMO-TACHOMETER.

When anemometers of the screw type are used for high velocities, there is danger that the vanes will be deformed and the velocity indications become unreliable, and for this reason cup anemometers are more suitable for out-door work. Wilhelm Morell, of Leipzig, has placed on the market an anemo-tachometer illustrated in the Deutsche Luftfahrer.[2] This is a Robinson anemometer with tachometer attached for aeronautical purposes, the tachometer being an instrument, usually actuated by centrifugal force like a steam engine flyball governor, so that velocities may be read at a glance from the position of a pointer. It will be noted that with a tachometer, in contrast to a revolution counter, no measurement of a time interval is required. The anemo-tachometer also has the advantage of all Robinson anemometers that the wind vane may be dispensed with.

According to a communication from Morell, his anemometers are calibrated in a wind tunnel, built in accordance with designs of Prof. Prandtl of the University of Göttingen, in which air currents up to 78 miles per hour (125 kilometers), can be obtained. It is stated that some of these instruments have been in constant use for two years without needing recalibration.

The anemo-tachometer, as well as other anemometers, should be attached to the aeroplane in such a manner that its indications are not influenced by the irregular and indeterminate wash of the machine and propeller. It has been proposed to lengthen the distance between the cups and the casing, so as to bring the cups above the upper supporting plane, while keeping the dial on a level with the pilot's line of vision. The objection to this lengthening is that it might change the friction and hence the indications of the instrument, and necessitate a special calibration.

What appears at first sight to be a solution of the difficulty, would be to provide the anemometer axis with a small electric generator, and use the electric voltage, thus generated to indicate speed of rotation by means of a voltmeter. We should anticipate, however, that electric indicating instruments, as at present constructed, would not long retain their accuracy when exposed to the vibrations on an aeroplane.

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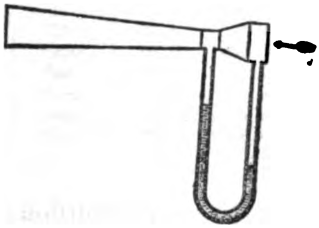
[1] Collected Researches, National Physical Laboratory, Vol. V, p. 174.
[2] Apr. 2, 1913, p. 168.

11. THE BOURDON-VENTURI ANEMOMETER.

The Venturi tube consists of a short converging inlet followed by a long diverging cone, the entrance and exit diameters being usually equal so that the tube may be inserted as a section of a pipe line. There is generally a short cylindrical throat. The converging part has somewhat the shape of a vena contracta, but its exact form is of little importance. The exit cone has a total angle of about 5°, this being found to give the minimum frictional loss for a given increase of diameter.



Venturi tube.

When a current of fluid passes through the tube, the pressure in the throat is less than at entrance to the converging inlet, by an amount which depends on the ratio of entrance to throat area, the density of the fluid, and the speed of flow. If the tube is provided with side holes and connections to a differential gauge by which this pressure difference may be observed, it constitutes a Venturi meter. The area ratio is a known constant for a given tube, so that when the density of the fluid is known the observed pressure difference may be used as a measure of the speed of flow. When the pressure difference is expressed as the height of a water column, it is known technically as the "head on Venturi."

Such an instrument may be used as an anemometer by pointing it so that the wind blows directly through it, and the observed head may then serve as a measure of the wind speed. Bourdon[1] employed the Venturi tube for this purpose in 1881, and it has been used recently as an aeroplane anemometer.

At a given speed, the observed head increases with the ratio α of entrance to throat area and the instrument may be made to give a much larger head than a Pitot tube. This is illustrated by the figures given in Table 5 for a tube in which $\alpha = 4$, the throat having half the diameter of the entrance. The data are for air at atmospheric pressure and 70° F. Column (2) gives the head which would be observed with a Pitot tube; column (3) that observed by Bourdon; and column (4) the ratio of (3) to (2).

[1] Annales des Mines, September and October, 1881; Comptes Rendus, 1882, p. 229.

TABLE 5.—*Comparison of Pitot and Venturi heads for a=4.*

(1) Wind speed.		(2) Pitot-tube head.		(3) Head on Venturi according to Bourdon.		(4) $\frac{\text{Col. 3.}}{\text{Col. 2.}}$	(5) Theoretical head on Venturi.	
Miles hour.	*Meters sec.*	*Ins.*	*Mm.*	*Ins.*	*Mm.*		*Ins.*	*Mm.*
10	4.47	0.05	1.3	0.17*	4	3.4	0.7	18
20	8.94	.19	4.8	.80	20	4.2	2.9	74
30	13.41	.43	10.9	2.30	58	5.3	6.8	173
40	17.88	.77	19.6	4.0*	102*	5.2	12.3	312
50	22.35	1.20	30.5	6.6*	168*	5.5	20.0	508
60	26.82	1.73	43.9	10.0*	254*	5.8	30.0	762
70	31.29	2.35	59.7	15.0*	381*	6.4	45.0	1,143
80	35.76	3.07	78.0	20.0*	508*	6.5	63.0	1,600
90	40.23	3.89	98.8	25.0*	635*	6.4	90.0	2,286

In figure 1 the line *H G* represents Bourdon's observations and the starred values in column (3) of Table 5 were read from the dotted extension of this curve. While this extrapolation can make no claim to accuracy, it appears from column (4) of Table 5 that a Venturi tube with a 2 to 1 diameter ratio would probably give at least five times as much head as a Pitot tube at ordinary aeroplane speeds.

The curve *F E* of figure 1 and the numbers in column (5) of Table 5 were found from equation (27) of Part 2, which is known experimentally to agree closely with the facts when the Venturi meter is inserted in a pipe line instead of being used as an anemometer with both ends free. Upon introducing the known values of k and ρ for air at one atmosphere and 70° F., equation (27) reduces to

$$S = 1720\sqrt{\frac{r^{\frac{10}{7}}(1-r^{\frac{2}{7}})}{\alpha^2 - r^{\frac{10}{7}}}} \text{ miles per hour.}$$

If the 1720 is replaced by 769, the result will be in meters per second.

What part of the great discrepancy between columns (3) and (5) of Table 5, or between *E F* and *G H* of figure 1, is to be ascribed to friction or other circumstances which make the Venturi tube act differently as an anemometer and as a flow meter, and what part to Bourdon's experimental arrangements and possible errors of observation, can not be decided without further investigation; but in any event, it is obvious that with the Venturi tube a much larger head is available than with a Pitot tube.

Since Bourdon wanted an anemometer for very low speeds, he increased the available head still farther by using two concentric tubes, the exit end of the inner one being at the throat of the outer, so that the suction there increased the speed through the inner tube and the fall of pressure at its throat. The proportions of the tubes which were adopted as giving the best results were as shown in Table 6.

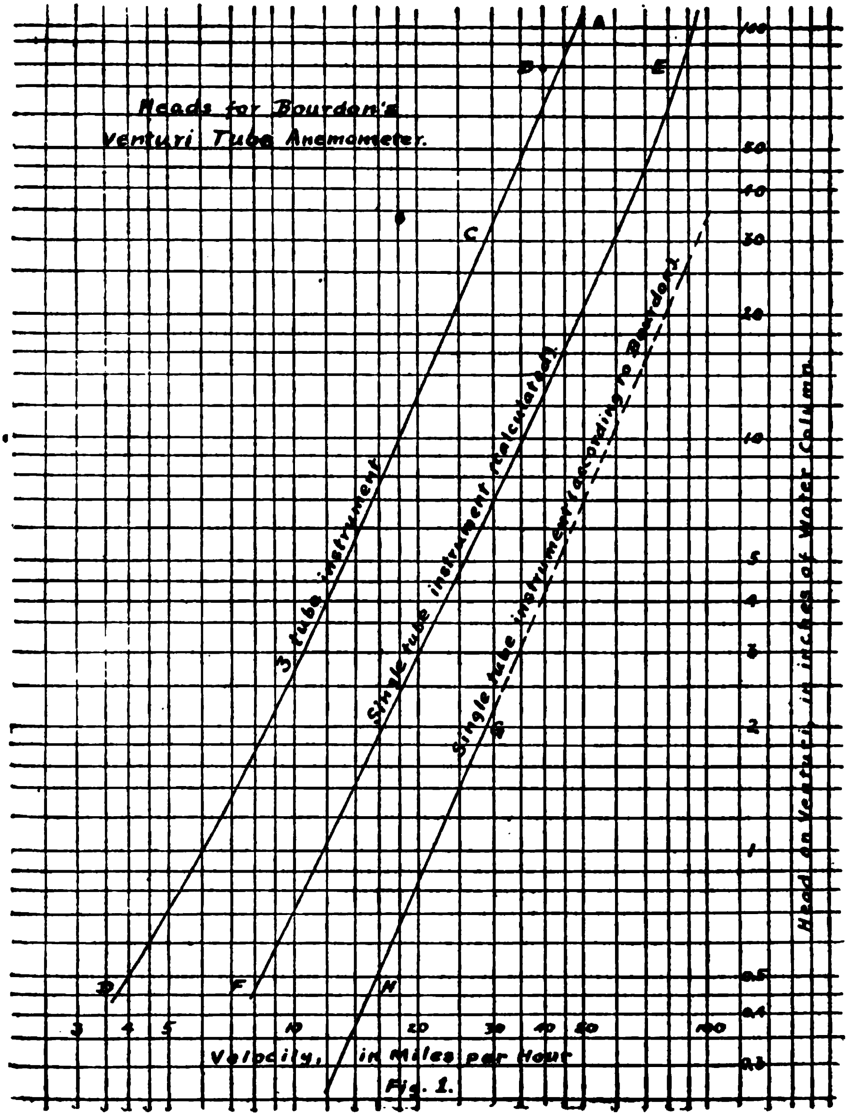


Fig. 1.

TABLE 6.—*Proportions of Bourdon's double Venturi tube anemometer.*

	Inner tube.	Outer tube.
Ratio of minimum to maximum diameter:		
(a) Of converging cone	0.31	0.56
(b) Of diverging cone	0.45	0.60
Double angle:		
(a) Of converging cone	34° 15	21° 38
(b) Of diverging cone	3° 45	4° 50
Relative throat diameters	1.0	6.2

No cylindrical throat piece was used with either tube, the converging and diverging cones being connected directly.

Bourdon also used a similar arrangement of three concentric tubes. The heads obtained with this, at various wind speeds, are shown on figure 1 by the curve D C and by the isolated point A. The point B is from tests of a 3-tube instrument by Brown Boveri & Co.[1]

The proportions of single-tube anemometers as used in modern French practice seem to be somewhat like those of Bourdon's inner tube. (See Table 6.) The length of tube in the anemometer made by Aera, of Paris, is 6.3 inches (160 mm.) or nearly the same as the length of the diverging cone of Bourdon's inner tube. Dorand[2] gives, without dimensions, a section of a Venturi-tube anemometer which indicates a ratio of throat to entrance diameter of about 0.2. The proportions proposed by Toussaint and Lepère[3] as a result of recent experiments are very similar to those of Bourdon's outer tube. (See Table 6.)

12. REMARKS ON THE SPECIAL CONDITIONS TO WHICH AEROPLANE ANEMOMETERS ARE SUBJECT.

A. *Weight and head resistance.*—These must both be small—the smaller the better. Accordingly we need not consider any essentially heavy instruments, such as those which require the use of electric batteries, nor instruments like large pressure plates which offer a head resistance of several pounds.

B. *Robustness.*—The very severe conditions of vibration preclude the possibility of using instruments which are not mechanically strong or which can not be made so without too great weight. Both the anemometer head proper, and the transmitting and indicating parts must be simple, light, strong, and free from the need of delicate adjustment or frequent testing.

C. *Position.*—The head must, so far as practicable, be out of reach of irregular currents and eddies and therefore at some distance from the indicator or dial in front of the pilot. The available positions are (*a*) in front of the center of the machine, (*b*) well above the upper planes over the pilot's head, (*c*) near one wing tip. Position (*a*) might be practicable and satisfactory in some cases but there is a possibility, unless the head were very far in front, that the readings might not be the same, at a given speed, during normal flight as when planing with the motor stopped. We have no information on this point. The influence of the body extends some distance ahead, a fact which should not be overlooked.[4] Position (*b*) would often require the construction of a special support, increasing the weight and head resistance. Position (*c*) seems the natural one to adopt if a transmission of the requisite length can be made satisfactory; but here again it should be noted that the disturbance due to a strut or wing begins some distance ahead of the leading edge.[5]

D. *Orientation.*—While most anemometers have to be pointed directly into the wind if they are to indicate its resultant velocity,

[1] Zeitschr. d. Ver. Deutscher Ingenieure, 1907, p. 1848.
[2] E. Dorand, La Technique Aeronautique, Nov. 1, 1911, p. 252.
[3] Rep. Brit. Adv. Com. for Aeronautics, 1912–13, p. 396.
[4] See, for example, the results of experiments on the Marienfelde-Zossen high-speed electric railway, The Electrician, June 17, 1904.
[5] See E. F. Relf, Rep. Brit. Adv. Com. for Aeronautics, 1912–13, p. 133.

what is needed in aviation is primarily the relative wind speed along a direction fixed with regard to the axis of the machine. The undesirable complication of mounting the anemometer head on a wind vane is therefore unnecessary and the head may be fixed. If information is required about motion perpendicular to this direction, it may be got from a wind vane.

E. *Independence of gravity.*—On account of the very considerable angles of heeling and pitching, it seems useless to consider any instrument which depends for its action on weights or liquid manometers. Any required forces must be applied by springs; or if pressures are to be registered, it must be by spring gauges. Furthermore, all parts of the instrument must be so balanced that the readings are not affected at all by gravity. This remark applies to the transmission and the indicator as well as to the head.

F. *Vertical acceleration and centrifugal force.*—Vertical acceleration acts merely as a change of the intensity of gravity. It will, therefore, have no effect on an instrument which is properly constructed in accordance with E, above.

Centrifugal force must be allowed for in a similar way by careful balancing of all movable parts so that the lateral acceleration of the whole machine during curved flight shall not influence the readings. This balancing in the transmission is equally necessary, whether forces are transmitted by rods or wires or pressures by fluids in tubes.[1]

13. DENSITY CORRECTIONS.

Before considering the effects of changes of air density on the indications of particular types of anemometer it will be well to see how great these variations are likely to be under working conditions. For this purpose we consult equation (6) of section 4, viz,

$$\rho = 1.327 \frac{B - 0.376\, PH}{460 + t} \qquad (6)$$

in which

ρ = the density of the air in pounds per cubic foot.
B = the barometric pressure in inches of mercury.
t = the temperature of the air in degrees Fahrenheit.
P = the pressure of saturated steam at t° in inches of mercury.
H = the relative humidity ($H = 1.0$ for saturated air).

The ranges we shall assume are: $B = 30$ to 20 inches, corresponding to a rise from sea level to about 10,000 feet altitude; $t = 0^\circ$ to 90° F.; $H = 0.0$ to 1.0, i. e., from complete dryness to saturation.

We may first consider the term 0.376 PH. Taking P from the steam tables we have

at	$t = 50^\circ$	70°	90°
$0.376\, P =$	0.136	0.278	0.533
$0.376\, P \times 0.5 =$	0.068	0.139	0.267

[1] For a discussion of the effect of vertical acceleration and centrifugal force on liquid manometers the reader may be referred to an article by H. Darwin, Aeronautical Journal, July, 1913, p. 170.

If we assume a constant relative humidity $H=0.5$, while in fact the humidity varies all the way from 0.0 to 1.0, the maximum error we can make in the value of 0.376 PH is 0.376 $P\times 0.5$, of which the values at 50°, 70°, and 90° are shown above. To find the percentage error which this assumption can introduce into the computed value of ρ, we must compare these errors with the value of B. The following table shows the maximum per cent. errors in ρ at 50°, 70°, and 90° F. and at 20 and 30 inches pressure which can be caused by assuming $H=0.5$.

	$t=50°$	$t=70°$	$t=90°$
$B=20$ inches	0.34%	0.70%	1.33%
$B=30$ inches	0.23%	0.46%	0.89%

Since a temperature of 90° F. will seldom or never prevail at an altitude where the pressure is as low as 20 inches, we may regard 1 per cent. as about the maximum possible error, and in the vast majority of cases the actual error will be less than 0.5 per cent. Now with the anemometers we need to consider, a given percentage error in the density causes only about half as much error in the speed S; and furthermore, an accuracy of 1 per cent. in measuring the speed of an aeroplane may be regarded as satisfactory. Hence the assumption of a constant relative humidity of 50 per cent. ($H=0.5$) is quite approximate enough for our purpose, and we adopt this assumption and thereby simplify equation (6) to the form

$$\rho=1.327\frac{B-0.19\ P}{460+t}\ \text{pounds per cubic foot.} \tag{8}$$

From equation (8) we may now compute a table of approximate values of the air density at various values of the barometric pressure B and the temperature t. It will be convenient to have the values expressed, not in pounds per cubic foot, but in terms of a standard air density, and for this the value $=0.07455$ has been chosen. This is the density at $B=29.92$ inches, $t=70°$ F., and $H=0.5$, conditions which are a fair average representation of those which are likely to prevail during anemometer tests. The values are shown in Table 7.

TABLE 7.—*Relative density D of air at B inches pressure, t° F., and 50 per. cent relative humidity, referred to air at 29.92 inches pressure, 70° F., and 50 per cent. relative humidity.*

$B=$	20″	22″	24″	26″	28″	30″
$t=0°$ F....	0.773	0.851	0.928	1.006	1.083	1.160
10°.....	.757	.833	.908	.984	1.060	1.135
20°.....	.741	.815	.889	.963	1.037	1.112
30°.....	.725	.798	.871	.943	1.016	1.088
40°.....	.710	.781	.853	.924	.995	1.066
50°.....	.696	.766	.835	.905	.975	1.045
60°.....	.681	.750	.818	.887	.955	1.023
70°.....	.667	.734	.801	.868	.935	1.003
80°......	.653	.719	.785	.850	.916	.982
90°.....	.639	.703	.768	.833	.897	.962

We have next to consider how these variations of density may affect the readings of an anemometer which has been tested under standard conditions.

A. *The Pitot tube.*—The Pitot tube formula may be written

$$S = \text{const} \times \sqrt{\frac{p_1 - p_2}{\rho}}$$

or for a standard density ρ_0

$$S_0 = A_0 \sqrt{p_1 - p_2}$$

At any other density, $\rho = D\rho_0$, we have

$$S = \frac{A_0}{\sqrt{D}} \sqrt{p_1 - p_2} = \frac{S_0}{\sqrt{D}} \qquad (9)$$

If the tube has been standardized at the density ρ_0 and the constant A_0 determined, or if the gage has been provided with a speed scale or a table for converting its readings at the standard density ρ_0 into speeds, the true speed at any other density ρ is found by multiplying the indicated speed by $\frac{1}{\sqrt{D}}$. Values of $\frac{1}{\sqrt{D}}$ computed from Table 7 are given in Table 8.

TABLE 8.—*Values of* $\frac{1}{\sqrt{D}}$ *for use in equation (9).*

$t°$ F.	Barometric height B in inches of mercury.					
	20″	22″	24″	26″	28″	30″
0	1.137	1.084	1.038	0.979	0.961	0.928
10	1.149	1.096	1.049	1.008	.971	.938
20	1.162	1.108	1.061	1.019	.982	.948
30	1.174	1.119	1.072	1.030	.992	.958
40	1.187	1.131	1.083	1.040	1.003	.968
50	1.199	1.143	1.094	1.051	1.013	.978
60	1.212	1.155	1.106	1.062	1.023	.989
70	1.225	1.167	1.117	1.073	1.034	.999
80	1.238	1.180	1.129	1.084	1.045	1.009
90	1.251	1.193	1.141	1.096	1.056	1.020

If the purpose of reading the anemometer is not, primarily, to ascertain the speed, but to judge of the wind pressures on the machine which determine the lift and the stresses, then the density correction should *not* be applied. For at any given angle of attack, the wind forces are very nearly proportional to the Pitot pressure; when the gauge shows a given reading, the wind forces are always the same; and from the standpoint of sustaining power and strength it is immaterial how the forces arise. Hence from the point of view of the aviator who is concerned with the safety of his machine, the

speed readings of the Pitot-tube anemometer correct themselves automatically—if the machine flies safely at a given speed and in air of a given density, it will be equally safe in air of any other density, regardless of pressure, temperature, and humidity if the Pitot-tube gauge gives the same reading.

B. *Pressure-plate anemometers.*—It would naturally be supposed that the readings of pressure plate anemometers would be affected by variations of air density in the same way as those of Pitot tubes. The theory of the subject, however, is not entirely clear, and it is difficult to interpret some of the experimental results which have been obtained.[1] In the absence of further investigation it would seem safest to make the density correction, when necessary, exactly as is done for the Pitot tube. If the readings are taken only for the sake of estimating the wind forces on the machine, the density correction is to be omitted, just as with the Pitot tube.

C. *The Bourdon-Venturi anemometer.*—If the results of Bourdon's experiments agreed closely with computations from the theoretical equation of the Venturi meter, we should feel justified in using that equation to compute density corrections to be applied to the readings of an instrument which had been tested at a standard air density. But the discrepancies shown by curves GH and EF of figure 1 are so large that we can not trust the theoretical equation at all for a Venturi tube used as an anemometer. It appears that further experimental investigations of this instrument are needed.

D. *Rotary anemometers.*—Regarding rotary anemometers, Jones and Booth[2] say:

> The principal advantage possessed by instruments of this type is that they read the actual travel through the air independently of variations in density.

It seems likely, however, that this independence is only approximate and not complete. The ratio of cup or vane speed to wind speed depends on the value of the least wind speed which will just keep the anemometer turning against friction. And since each vane or cup when moving very slowly acts as a pressure plate, it seems that the wind speed required in order to furnish the torque for very low speeds of rotation must depend on the air density. Hence it seems probable that at higher speeds the action of instruments of the Robinson or of the screw type is somewhat influenced by air density. Exact information on this is lacking.

14. COMPARISON OF TYPES OF ANEMOMETER.

Anemometers in general might be compared from various points of view; but since our purpose is strictly practical, we shall at once exclude from the discussion any instrument which can not be made satisfactory on the score of (*a*) robustness combined with lightness, (*b*) independence of gravity, and (*c*) flexibility of transmission, permitting the head to be placed at a distance from the indicator in front of the pilot's seat. There seem then to remain for discussion the Pitot tube, the pressure plate, the Venturi tube, and the Robinson anemometer.

A. *The Pitot tube.*—This has been the most studied, and we can speak of it with more certainty than of the others. The head is

[1] See Rayleigh, Rep. Brit. Adv. Com. for Aeronautics, 1910–11, p. 26.
[2] Aeronautical Journal, July, 1913, p. 192.

simple and may be placed in any position; and the transmission of the pressure through tubes presents no obvious difficulties. The prime defect of the instrument is the smallness of the pressure available for actuating the indicator. While sensitive liquid gauges may be used under some circumstances, anything but a spring gauge seems out of the question for all-round use. The problem with the Pitot tube is to make a satisfactory spring gauge which shall at the same time be sufficiently sensitive and so robust as to be reliable. The problem looks difficult, but may not be insoluble.

B. *The pressure plate.*—By an increase of size, the pressure plate may be made to give as large a force as is desired, the limit being set by the amount of head resistance which it is considered permissible to devote to an anemometer. Transmission by wires under tension might be practicable but would be liable to get out of order and to be seriously disturbed by vibration. Transmission by means of liquid pressure might be managed but would introduce complications, and the development of the instrument in this form would demand a great deal of experimentation. In spite of its attractiveness and apparent simplicity at first sight, the pressure plate does not, on the whole, seem very promising as a practical aeroplane instrument.

C. *The Bourdon-Venturi anemometer.*—The Venturi tube furnishes a pressure difference and the transmission problem is simple, as it is with the Pitot tube. But the pressure difference may be made so large that the problem of making a satisfactory spring gauge is vastly simpler than with the Pitot tube, and should not present any insuperable difficulties. A more important doubt arises in connection with the density correction. Since it is impracticable to test an anemometer at low-air densities by the ordinary methods, and since Bourdon's results differed greatly from what might have been expected on theoretical grounds, the instrument should be used with caution, if high altitude flights are in question, until we know more about its practical behavior. On the other hand, it appears to be satisfactory at ordinary air densities,[1] and it seems to be an instrument of great promise and one of which the practical development should be pushed along.

D. *The Robinson anemometer.*—The weak point of the Robinson anemometer is lack of flexibility in the transmission. In the form of Morell's anemo-tachometer it indicates speed through the air nearly independently of the air density. But since the main purpose of knowing this speed is for finding the total distance traveled, it would seem as if the ordinary method of registering the total number of turns would, in practice, be more useful than the attachment of a tachometer to give instantaneous speeds.

Having now discussed some of the mechanical characteristics of the four types of instrument we may take another standpoint and, assuming that a mechanically satisfactory instrument of each type can be constructed, ask whether one presents any advantages over another. The answer to this question depends on why we want to know the speed.

If what is wanted is to estimate the distance traveled through the air, some form of Robinson anemometer seems to be the thing to use, because it is independent of air density, to a first approximation, at

[1] See Eiffel, The Resistance of the Air, p. 234.

all events. The other three types of instrument will all require to have a density correction applied to their readings, if the air density is far different from that during standardization, and they are thus at a disadvantage.

But it appears that the speed through the air is, in general, not itself the important quantity sought; for at best it does not tell us the speed over the ground until it is compounded with the speed of the wind which may happen to be blowing. A more important use of the anemometer is not properly as a speedometer but as a dynamometer, i. e., as an instrument for indicating the air forces on the machine. For this purpose, any instrument such as the anemo-tachometer which gives the speed without reference to the density will require a density correction to its readings, whereas the Pitot tube gives just what is wanted, the allowance for density being already present in its uncorrected readings, so that equal readings mean equal pressures, whatever the density may be. The pressure plate falls in the same class as the Pitot tube. Of the Bourdon-Venturi anemometer we can say very little until the instrument has been further studied, but it seems likely that it also will act rather as a dynamometer than as a speedometer, if its readings are not corrected for variations of air density.

Still another question which may be asked is, What sort of mean speed does a given anemometer indicate when exposed to a gusty wind? In regard to this question, the four types under consideration fall into the same grouping as before. With the Pitot tube, the pressure plate, or the Venturi tube, the pressure difference or the force depends on the square of the wind speed, and the mean reading of any of these instruments in a wind of varying speed will therefore give not the arithmetical mean speed but the root-mean-square speed, which is what determines the mean wind forces on the aeroplane. The anemo-tachometer, on the other hand, will probably indicate something between the arithmetical mean and the root-mean-square speed. If it had no inertia it might be made to indicate the arithmetical mean, but the effects of inertia in causing lag or lead will probably make the mean reading of the instrument in a wind of variable strength somewhat higher than it would be in the absence of inertia. The fact that this might result in a slight overestimate of the total travel will hardly be of any moment, in view of the impossibility, for the aviator, of measuring and allowing for the true velocity of the wind with respect to the earth's surface.

REPORT No. 2.

PART 2.

THE THEORY OF THE PITOT AND VENTURI TUBES.

By E. Buckingham.

1. THE ENERGY EQUATION FOR STEADY ADIABATIC FLOW OF A FLUID.

Let a fluid be flowing steadily along a channel with impervious and nonconducting walls, from a section A to a section A_1, the areas of the sections perpendicular to the direction of flow being also denoted by A and A_1. By saying that the flow is "steady" we do not mean that it occurs in stream lines and without turbulence. We mean merely that it is "sensibly" steady; i. e., that such variations of speed, direction of motion, pressure, etc., as may occur at any point in the stream as a result of turbulence are so rapid that our measuring instruments do not respond to them, but indicate only time averages; and that these time averages are constant at any fixed point within the channel. Values of a property of the fluid, or of any other quantity such as speed, "at a point," are therefore to be understood as time averages over a time which is long compared with the speed of variation of the quantity to be measured, though it may appear short in the ordinary sense.

Let θ, p, v, ϵ, T, respectively, be the absolute temperature, static pressure, specific volume, internal energy per unit mass, and kinetic energy per unit mass, at the entrance section A. By the "static pressure" is meant the pressure which would be indicated by a gauge moving with the current. Let θ_1, p_1, v_1, ϵ_1, T_1 be the corresponding quantities at the exit section A_1. Both sets of values are to be understood as averages over the whole section, as well as time averages in the sense explained above. The two sections shall be at the same level, so that the passage of fluid from A to A_1 does not involve any gravitational work.

As a unit mass of fluid crosses A, the work pv is done on it by the fluid following; and as it crosses A_1 it does the work p_1v_1 on the fluid ahead. Since the walls of the channel are nonconducting, no heat enters or leaves the fluid between A and A_1; hence the total energy, internal plus kinetic, increases (or decreases) by an amount equal to the work done on (or by) the fluid, and we have

$$pv - p_1v_1 = (\epsilon_1 + T_1) - (\epsilon + T)$$

or

$$T - T_1 = (\epsilon_1 + p_1v_1) - (\epsilon + pv) \qquad (1)$$

So far no assumptions have been made and equation (1) is rigorously correct for adiabatic flow between two sections at the same level. Internal heating by skin friction or the dissipation of eddies is merely a conversion of energy from one form into another and not an addition of energy; hence it does not affect the validity of equation (1) and need not appear in it.

2. INTRODUCTION OF THE MEAN SPEED INTO THE ENERGY EQUATION.

Let Q be the volume of fluid which crosses the section A per unit time, and let $S = Q \div A$; then S is the arithmetical mean, over the section, of the component velocity normal to A and along the channel. Let Q_1 and S_1 be the corresponding values at A_1. Measuring kinetic energy, as well as work and internal energy, in normal mass-length-time units, we then set

$$T - T_1 = \frac{1}{2}(S^2 - S_1^2) \tag{2}$$

and proceed to substitute this expression for $(T - T_1)$ in equation (1).

This substitution is indispensable to further progress, but it involves an assumption which destroys the rigor of all further deductions. The deductions are, nevertheless, very approximately confirmed by experiment, and it is therefore worth while to examine the assumption.

If there were no turbulence and if the speed were uniform over each section, we should have the two separate equations

$$\left.\begin{aligned} T &= \frac{1}{2}S^2 \\ T_1 &= \frac{1}{2}S_1^2 \end{aligned}\right\} \tag{3}$$

and equation (2) would be exact. If there is no turbulence but the speed of flow is nonuniform, approaching zero at the walls, as it must where the channel has material walls, equations (3) will not be satisfied, but we shall have $T > \frac{1}{2}S^2$ and $T_1 > \frac{1}{2}S_1^2$, because the mean square speed, which determines the kinetic energy, is always greater than the arithmetical mean speed S when the distribution over the section is not uniform. With a round pipe and nonturbulent flow $T = \frac{3}{2}S^2$ instead of $\frac{1}{2}S^2$.

In nearly all practical cases the flow of fluids is turbulent and the relation of the whole kinetic energy, including that of the turbulence, to the arithmetical mean normal component of the speed at the given section will depend on the amount of turbulence. It is impossible to say what the relation will be further than that the kinetic energy of eddies and cross currents tends to increase the error which would be involved in assuming equations (3), while, on the other hand, the fact that with increasing turbulence the speed becomes more nearly uniform over a cross section tends to decrease the difference between the mean square and the arithmetical mean of the component normal to any section.

The assumption involved in using equation (2) is not, however, so violent as that which would be involved in using equations (3) separately. For equations (3) are equivalent to

$$T-\tfrac{1}{2}S^2=T_1-\tfrac{1}{2}S_1^2=O$$

whereas equation (2) is satisfied if

$$T-\tfrac{1}{2}S^2=T_1-\tfrac{1}{2}S_1^2 \qquad (4)$$

no matter what the value is. Equation (4) and its equivalent (2) are satisfied if the error in assuming equations (3) to hold is the *same* at both sections without vanishing or even being small. This will occur if the kinetic energy of turbulence is the same at both sections and if also the speed distributions over the two sections are such that the arithmetical mean normal speed is the same fraction of the mean-square normal speed at both. While therefore it is evident that the use of equations (3) separately might lead to conclusions at variance with facts, equation (2) may nevertheless be nearly fulfilled in practice. The agreement with observation of deductions from equations (2) and (1) shows that in many ordinary cases the error committed by treating equation (2) as exact is in reality quite insignificant.

For geometrically similar channels, the percentage error of equation (2) depends only on $\frac{DS}{\nu}$, in which ν is the kinematic viscosity of the fluid and D a linear dimension of the channel. With a given fluid in a given channel increasing S increases the turbulence, but it is not evident how this will affect the percentage error, $\frac{2T-S^2}{S^2}$, if at all. Hence, it seems possible that although turbulence increases with $\frac{DS}{\nu}$, the *percentage* error in assuming equation (2) may not increase but remain constant or even decrease. On the other hand, at a given speed S, if $\frac{DS}{\nu}$ is increased by increasing D or diminishing ν, the turbulence and the value of $\frac{2T-S^2}{S^2}$ will be increased and there will be a greater chance that equation (2) may be sensibly in error. At a given mean axial speed S we must therefore be prepared to find greater discrepancies between experiment and results deduced from equation (2) for large channels and fluids of low kinematic viscosity than for the opposite conditions.

We shall now proceed as if equation (2) were rigorously exact, and by combining it with equation (1) we obtain

$$\tfrac{1}{2}(S^2-S_1^2)=(\epsilon_1+p_1v_1)-(\epsilon+pv) \qquad (5)$$

an equation which serves as the point of departure for the theory of the Pitot tube, the Venturi meter, the steam-turbine nozzle, and various other devices in which a stream of fluid is retarded or accelerated adiabatically.

3. ISENTROPIC FLOW OF AN IDEAL GAS.

If the physical properties of the fluid have been sufficiently investigated and if a sufficient number of quantities are measured at each of the two sections, the value of $(\epsilon+pv)$ may be computed for each section and the value of $(S^2-S_1^2)$ found from equation (5), to the degree of approximation permitted by the assumptions which have been discussed above. A process somewhat of this nature is pursued in the design of steam-turbine nozzles, $(\epsilon+pv)$ being then the quantity known as the total heat of steam.

But when the fluid is a gas, it is usual to proceed with deductions from equation (5) by the aid of two further assumptions which enable us to compute variations of ϵ and v from observations of p alone. The first of these assumptions is that the fluid behaves sensibly as an ideal gas defined by the equations

$$pv=R\theta \tag{6}$$

$$\epsilon=\epsilon_0+C_v\,(\theta-\theta_0) \tag{7}$$

in which C_v is the specific heat at constant volume, and ϵ_0 is the internal energy at the standard temperature θ_0. The properties of ordinary gases, such as air, carbon dioxide, or coal gas, when far from condensation, are nearly in conformity with equations (6) and (7), and for such fluids no serious error is involved in making the assumption mentioned, unless very great variations of pressure and temperature are under consideration. Equations (6) and (7) imply also the relation

$$C_p=C_v+R \tag{8}$$

in which C_p is the specific heat at constant pressure.

The second assumption is that during the simultaneous changes of pressure and temperature in passing from A to A_1 the familiar isentropic relation for an ideal gas, viz,

$$\frac{\theta_1}{\theta}=\left(\frac{p_1}{p}\right)^{\frac{k-1}{k}} \tag{9}$$

remains satisfied, k representing C_p/C_v. This assumption is, of course, not exact, for while we have stipulated that the flow shall be adiabatic, the internal heating, due to viscosity causes an increase of entropy. The assumption amounts, therefore, to assuming that this irreversible internal heating is not enough to cause any sensible increase of the temperature at A_1 over what it would be if there were no internal heating at all.

The foregoing assumptions enable us to put equation (5) into a more available form. By substituting from (6) and (7) into (5), and using (8), we have

$$\frac{1}{2}\,(S^2-S_1^2)=C_p\,(\theta_1-\theta) \tag{10}$$

By means of (9) and (6), this may be written

$$\frac{1}{2}\,(S^2-S_1^2)=\frac{C_p}{R}pv\left[\left(\frac{p_1}{p}\right)^{\frac{k-1}{k}}-1\right]$$

and by (8) we get $C_p/R = \frac{k}{k-1}$ so that we have

$$\frac{1}{2}(S^2 - S_1^2) = \frac{k}{k-1} pv\left[\left(\frac{p_1}{p}\right)^{\frac{k-1}{k}} - 1\right] \tag{11}$$

which is the usual form of equation (5) for isentropic flow of an ideal gas. If the speed is known at either section, equation (10) enables us to find the speed at the other from a knowledge of C_p and an observation of the difference of temperature; while equation (11) gives us similar information in terms of the pressures at A and A_1 if the density and the ratio k are known. We shall apply this equation to both the Pitot tube and the Venturi meter.

4. THE THEORY OF THE PITOT TUBE.

To treat the Pitot tube, we consider the fluid which is approaching the dynamic opening. Starting at a point so far upstream that the presence of the Pitot tube produces no sensible disturbance there, a particle of fluid approaches the dynamic opening, slows down, and mixes with the permanent high-pressure cap of nearly stationary fluid, which covers the dynamic opening and communicates with the differential gauge through the impact tube. The same particle, or another indistinguishable from it, emerges from the cap and, being accelerated by the now positive pressure gradient, flows on along the impact tube, finally acquiring a sensibly constant speed when it has reached a region of sensibly constant pressure. We wish to apply equation (5) to this motion if we can find a plausible way of doing so.

Starting with the contour of a small plane area, in the undisturbed current and perpendicular to its general direction, we construct, in imagination, a tubular surface of which the sides are at every point parallel to the mean direction of motion of the fluid past that point, as found by averaging with regard to time. If the motion is not turbulent, this tube is a tube of flow and no fluid passes in or out through its sides. If the motion is turbulent, as it nearly always is in practice, the *same* fluid does not flow continuously along the tube as it would if the walls were impervious. On the contrary, particles of fluid are continually leaving the tube in consequence of the turbulent time-changes of the direction of motion at any fixed point; and these particles are continually replaced by others, of the same total mass, which enter from without the tube. But on the whole, the particles which enter have the same average component velocity along the tube as those which leave; for unless this were true we could, merely by *imagining* the tubular surface, generate within the fluid a particular filament which was moving, on the whole, faster or slower than the surrounding fluid. We conclude that the net effect of turbulence is the same as if the imaginary tube walls were made rigid and perfectly reflecting for mechanical impact without exerting any skin friction on the fluid flowing along them.

If the whole current of fluid is at a sensibly uniform temperature across its general direction, no heat passes in or out through the tubular surface, and equation (5) may be applied as though we had an impervious nonconducting channel to deal with. Furthermore, if the tube is of small section, the axial speed, averaged with regard

to time, will be the same at all points of any one cross section. Hence the application of equation (5), involving the assumption of equation (2) or (4), is better justified than for a material tube in which skin friction would cause the axial speed to be nonuniform over any section.

We now consider such an imaginary tube, starting in the undisturbed fluid some distance upstream from the dynamic opening of the Pitot tube, passing into the high-pressure cap over the opening and emerging again at the edge of the opening, to continue its course along the side of the impact tube. The portion of the imaginary tube which passes through the high-pressure cap may be regarded as an enlargement of cross section at which the mean axial speed is so reduced that its square is negligible in comparison with the square of the speed at distant points. If we let A be a section at some distance upstream and A_1 be the section of the tube where it passes through the high-pressure cap, S_1^2 is negligible in comparison with S^2 and equation (5) gives us

$$S=\sqrt{2[(\epsilon_1+p_1v_1)-(\epsilon+pv)]} \tag{12}$$

in which S is the speed of the undisturbed current; ϵ, p, and v refer to conditions in the undisturbed current; and ϵ_1, p_1, v_1 refer to conditions in the dynamic opening. The static pressure, which the static opening is designed to receive and transmit to the gauge, is p; while the pressure received by the dynamic opening is that in the permanent high-pressure cap, or p_1.

Equation (12) is the general form of the Pitot tube equation for any fluid, whether compressible or not. In the case of a liquid, the internal energy and specific volume are not appreciably affected by the very small pressure variations involved, so that we have $\epsilon_1=\epsilon$ and $v_1=v$ and equation (12) reduces to

$$S=\sqrt{2v\ (p_1-p)}=\sqrt{2\,\frac{p_1-p}{\rho}} \tag{13}$$

ρ being the density of the liquid. If the pressure difference is expressed as a head h of liquid of density d, we have $p_1-p=ghd$ and equation (13) takes the form

$$S=\sqrt{2g\,\frac{d}{\rho}\,h} \tag{14}$$

the usual form of the Pitot tube equation for a perfect or ideal tube.

Even when the fluid is a gas, if S is small and (p_1-p) therefore also small, ϵ_1 and v_1 are nearly the same as ϵ and v so that equations (13) and (14) remain approximately correct—admitting all the assumptions made—though it is not evident how close the approximation will be. But if the speed and the pressure difference are great enough to cause sensible compression, we must return to equation (5) and introduce the conditions for adiabatic flow of a gas, as was done in section 3 in arriving at equation (11). The fact that equation (14) does agree well with observations on gas currents at moderate speeds, shows that no great error is involved in neglecting compressibility

and justifies us in going on to find a closer approximation by treating the gas as ideal and thereby using an approximation to the compressibility.

Assuming, then, that equation (11) is applicable to the imaginary current tube now under discussion, we have, by setting $S_1^2=O$, the equation

$$S=\sqrt{\frac{2k}{k-1}\,\frac{p}{\rho}\left[\left(\frac{p_1}{p}\right)^{\frac{k-1}{k}}-1\right]} \tag{15}$$

If we now set $\frac{p_1}{p}=1+\Delta$ and $\frac{k-1}{k}=n$ we have

$$\left(\frac{p^1}{p}\right)^{\frac{k-1}{k}}-1=n\Delta\left\{1+\frac{n-1}{2}\,\Delta+\frac{(n-1)\,(n-2)}{1\cdot2\cdot3}\Delta^2+\text{etc.}\right\}$$

Setting the $\{\ldots\ldots\}=X^2$, substituting in equation (15), and noticing that $n\,\Delta=\frac{k-1}{k}\,\frac{p_1-p}{p}$ we have

$$S=X\sqrt{2\,\frac{p_1-p}{\rho}} \tag{16}$$

which differs from equation (13), obtained by disregarding compressibility, only in the correction factor

$$X=\left\{1+\frac{n-1}{2}\Delta+\frac{(n-1)\,(n-2)}{1\cdot2\cdot3}\Delta^2+\frac{(n-1)\,(n-2)\,(n-3)}{1\cdot2\cdot3\cdot4}\Delta^3+\cdots\right\}^{\frac{1}{2}} \tag{17}$$

The quantity $\Delta=\frac{p_1-p}{p}$ is the fractional rise of pressure at the mouth of the impact tube: hence it is, in practice, always a small quantity. The value of k for gases is always between $\frac{5}{3}$ and 1, so that $n=\frac{k-1}{k}$ is always between $\frac{2}{5}$ and 0. Accordingly the terms of X containing Δ are alternately negative and positive and when Δ is small the series converges rapidly, the sum of all the terms in Δ being nearly equal to the first term alone, so that if the first is negligible the sum is negligible and X may be set equal to unity.

The ratio of the specific heats of air is 1.40. Hence $n=\frac{2}{7}$ and we have

$$X=\left\{1-\frac{5}{14}\Delta+\frac{10}{49}\Delta^2-\frac{95}{686}\Delta^3+\text{etc.}\right\}^{\frac{1}{2}} \tag{18}$$

If an error of y per cent. in S is permissible, an error of y per cent. may also be allowed in the correction factor X and the value of Δ may be, at most, such as to make $\frac{5}{28}\,\Delta=\frac{y}{100}$ or $\Delta=0.056y$. For any assigned values of the error y per cent. in the speed, the value of S can be found from equation (13).

Let us suppose, for example, that the Pitot tube is to be used for measuring the speed of an aeroplane and that an accuracy of 0.5 per cent. is sufficient. Then we have $\Delta = 0.028$ and $p_1 - p = 0.028\ p$. To find what speed would give this head on the differential gauge, we set $p = 1$ atmosphere $= 1.013 \times 10^6$ dynes/cm.^{2} and $\rho = 0.0013$ gram/cm.,^{3} and substitute in (13), the result being $S = 66.1$ m./sec. $= 212$ ft./sec. $= 148$ miles/hour. Since an accuracy of better than 1.0 per cent. can hardly be demanded of an aeroplane speedometer, it is evident that for all ordinary speeds of flight, no correction for compressibility is needed and equations (13) and (14) may be used.

It is of course a simple matter to compute values of the correction factor X for various speeds; but in view of the uncertainties and assumptions involved in the theory, the results would have a misleading appearance of accuracy and would not in fact be worth the labor of computation. What has been shown is sufficient, namely, that if a Pitot tube does not measure the speed of an aeroplane correctly the error is not due to neglecting the compressibility of the air.

5. THE THEORY OF THE VENTURI METER.

The Venturi meter is a channel of varying cross section, and we may apply to it the general equations of flow which have already been developed. In doing so, we shall let A be the entrance section of the meter where p is measured, and A_1 be the throat section at which the diminished pressure p_1 is observed. We have to use equation (5).

If the meter is used for measuring the flow of a liquid of density ρ we may set $\epsilon_1 = \epsilon$ and $v_1 = v$ as we did in treating the Pitot tube, and equation (5) then gives us

$$S_1^2 - S^2 = 2\,\frac{p - p_1}{\rho} \tag{19}$$

Neither S nor S_1 vanishes; but in addition to (19) we have the equation of continuity which for a fluid of constant density may be written

$$S_1 A_1 = SA \tag{20}$$

and (19) and (20) together enable us to find either S or S_1. If we represent the area ratio by a single symbol

$$\frac{A}{A_1} = \alpha > 1 \tag{21}$$

we have

$$S = B\sqrt{2\,\frac{p - p_1}{\rho}} \tag{22}$$

where

$$B = \sqrt{\frac{1}{\alpha^2 - 1}} \tag{23}$$

and B is a constant characteristic of the given meter.

Comparing (22) with (13), the equation for the Pitot tube in a liquid, we see that they differ only by the factor B which depends on

the area ratio α. If $\alpha = \sqrt{2}$, $B = 1$ and the observed Venturi pressure difference $(p - p_1)$ will be the same as would be shown by a Pitot tube with its dynamic opening in the entrance of the meter. For various values of the ratio $\frac{D}{D_1}$ of entrance diameter to throat diameter we have the following values of B:

$\frac{D}{D_1}=$	1.5	2.0	2.5	3.0	4.0
$\alpha=$	2.25	4.00	6.25	9.00	16.00
$B=$	1.569	3.874	6.170	8.944	15.77

Evidently, the Venturi pressure difference may easily be made much larger than the Pitot pressure difference at the entrance speed and the gauge reading be made much more sensitive.

If the fluid is a gas instead of a liquid, compressibility will still be negligible at sufficiently low speeds, as for the Pitot tube, and equation (22) may be used; but in general the compressibility must be allowed for. To treat the flow of a gas, we have to make the same assumptions as in section 3, namely, that the gas is sensibly ideal and that the flow from the entrance section A to the throat A_1 is sensibly isentropic, the combined effect of heat conduction to or from the walls of the meter, and of internal heating in the gas itself, being insignificant. We then have to apply equation (11) to the case in hand, and if for simplicity we represent the pressure ratio by a single symbol and write

$$\frac{p_1}{p} = r < 1 \tag{24}$$

we have by equation (11)

$$S_1^2 - S^2 = \frac{2k}{k-1} \frac{p}{\rho}\left[1 - r^{\frac{k-1}{k}}\right] \tag{25}$$

ρ being the density of the gas at the pressure p as it crosses the entrance section.

To combine with (25) we have the equation of continuity

$$S_1 A_1 \rho_1 = SA\rho$$

and if we remember that during isentropic compression or expansion of an ideal gas pv^k remains constant, the equation of continuity may be written

$$S_1 = \frac{\alpha}{r^{1/k}} S \tag{26}$$

By using (26) to eliminate S_1 from (25) we now obtain the equation

$$S = \left\{\frac{2k}{k-1} \frac{r^{2/k}}{\alpha^2 - r^{2/k}} \frac{p}{\rho}\left(1 - r^{\frac{k-1}{k}}\right)\right\}^{\frac{1}{2}} \tag{27}$$

by means of which the entrance speed S may be computed from the observed pressure ratio $r = p_1/p$ when the area ratio α and the properties of the gas are known. Since we are treating the gas as

ideal, p/ρ is, for any given gas, proportional to the absolute temperature θ at the entrance section, and we may write $\frac{p}{\rho}=\frac{p_0}{\rho_0}\frac{\theta}{\theta_0}$, ρ_0 being the density of the gas at the standard pressure p_0 and temperature θ_0.

For air, $\frac{C_p}{C_v}=k=1.40$ and if we insert the known value of ρ_0 at 1 atmosphere and 0° C. and set

$$S=Y\sqrt{\frac{\theta}{\theta_0}} \tag{28}$$

where

$$Y=\left\{\frac{2k}{k-1}\cdot\frac{r^{2/k}}{\alpha^2-r^{2/k}}\left(1-r^{\frac{k-1}{k}}\right)\frac{p_0}{\rho_0}\right\}^{1/2}$$

we have the values of Y shown in the following table for various pressure ratios r and for meters in which the throat diameter is $\frac{1}{2}$, $\frac{1}{3}$, or $\frac{1}{4}$ of the entrance diameter, i. e., $\alpha=4$, 9, or 16. If t is the temperature at entrance, on the centigrade scale $\frac{\theta}{\theta_0}=\frac{273+t}{273}$ while if t is measured on the Fahrenheit scale,

$$\frac{\theta}{\theta_0}=\frac{460+t}{492}.$$

THE VENTURI METER FOR AIR.

Values of Y in $S=Y\sqrt{\frac{\theta}{\theta_0}}$

S=Speed at entrance to meter $\alpha=\frac{A}{A_1}=\frac{\text{entrance area}}{\text{throat area}}$

r=throat pressure÷entrance pressure=p_1/p θ=absolute temperature of air at entrance.

θ_0=absolute temperature of ice point.

Values of Y.

r	$\alpha=4$			$\alpha=9$			$\alpha=16$		
	M./sec.	Ft./sec.	Mile/hour.	M./sec.	Ft./sec.	Mile/hour.	M./sec.	Ft./sec.	Mile/hr.
0.9998	1.44	4.74	3.23	0.626	2.05	1.400	0.350	1.150	0.784
.999	3.23	10.60	7.23	1.40	4.59	3.13	0.784	2.57	1.753
.995	7.21	23.65	16.13	3.12	10.24	6.98	1.75	5.74	3.91
.99	10.16	33.34	22.7	4.40	14.11	9.85	2.47	8.09	5.52
.98	14.3	46.48	32.0	6.19	20.3	13.85	3.47	11.38	7.76
.95	22.2	72.8	49.6	9.62	31.6	21.5	5.39	17.7	12.06
.90	30.4	99.8	68.0	13.2	43.4	29.6	7.41	24.3	16.57
.80	40.2	131.7	89.8	17.5	57.5	39.2	9.82	32.2	22.0
.60	48.1	157.9	107.6	21.1	69.3	47.2	11.86	38.9	26.5

Computed on the assumptions $pv=R\theta$, C_v=constant, $\frac{C_p}{C_v}=1.400$.

$p_0=1.01323\times10^6$ *dyne/cm²*.

$\rho_0=0.0012928$ gm cm³ at 760 mm. and 0° C

REPORT No. 3.

REPORT ON INVESTIGATIONS OF AVIATION WIRES AND CABLES, THEIR FASTENINGS AND TERMINAL CONNECTIONS.

By JOHN A. ROEBLING'S SONS CO., TRENTON, N. J.

REPORT No. 3.

REPORT COVERING INVESTIGATIONS OF AVIATION WIRES AND CABLES, THEIR FASTENINGS AND TERMINAL CONNECTIONS.

By John A. Roebling's Sons Co.

In reference to our investigations of aviation wires and cables, their fastenings and terminal connections for stays, we have failed to find from past practice anything that would allow us to determine the best lines on which to proceed; therefore our study is not limited to any one stay design.

In making our investigation we have aimed to eliminate the use of acid and solder, imperfect bends, flattening of cable on bends, injury to wire, strand, and cord due to unskillful handling of material in the field; and based on our study of present methods of manufacture of aeroplanes we believe it is possible to manufacture the complete stay here at the factory, proof test same to 50 per cent of its ultimate strength, measure same under stress, and therefore eliminate any uncertainty as to strength of terminal connection, length of stay, and workmanship.

On this basis our research covered not only the terminal connection for shop attachment, but also a connection that would allow repairs to be made in the field without requiring the use of blow torch and solder, and from the following tests it will be readily seen that the development eliminates any doubt on this point.

We find present practice considers "the solid wire stay," consisting of one wire of suitable diameter and known to the trade as "aviation wire"; "the strand stay," consisting of either 7 or 19 wires stranded together and known to the trade as "aviator strand"; also "the cord or rope stay," consisting of 7 strands twisted together forming a rope, the strands being either 7 wires or 19 wires; and the rope known to the trade as "aviator cord."

THE SOLID WIRE STAY.

PLATE NO. 1.

Figure 1.

Figure 1 shows the type most generally in use. An eye or loop is formed in tinned aviator wire and a ferrule made by wrapping a thin flat strip around both wires. The free end of the wire is then bent back over the flat ferrule, holding it in place, and the whole terminal dipped in solder. This type of terminal is far from being satisfactory. Its mechanical strength is low and variable. The process of soldering involves the possibility of establishing a source of corrosion, as well as injuring the quality of the wire. The making of such a terminal is almost necessarily a factory proposition and provides no means for quick and efficient field replacements.

Figure 2.

The standard terminal in Europe is shown in figure 2. This consists of an oval spring wire ferrule applied in almost the same manner as the flat wire ferrule in figure 1. Particular emphasis is placed on the method of forming the eye in the stay before applying the ferrule. Radius of curve at "A" and "B," figure 2, must be exactly the same as radius at "C." This is called a perfect eye. No solder is used. The ferrule is made of wire of the same size as wire in stay and is "spring" quality. Nine convolutions constitute the standard length of ferrule. The hole in the ferrule is oval and a snug fit for the two wires forming the eye of stay. Both wire and ferrule are tin coated. The free end of the wire is bent back over the ferrule and is not fastened in any way. This holds the ferrule firmly against the shoulder at "A" and "B."

Tests made on stays having this type of terminal did not show very satisfactory results. Eighty per cent of the tests showed an efficiency of less than 65 per cent, the free end of the wire slipping through the ferrule at failure of the stay. In the remaining 20 per cent of the tests the wire broke at "A," the stays having an average efficiency of 68 per cent of the total strength of the wire.

Figure 3.

Figure 3 shows eye having radii "A" and "B" different from "C," which is not allowed in foreign specifications and practice. Tests made on terminals having an eye formed as in figure 3 always resulted in pulling through the free end of the wire at low efficiency.

Figure 4.

In order to determine whether the direction of pitch of the spiral spring ferrule had any influence in determining the efficiency of the stay, sample terminals having left-hand ferrules as in figure 2 and right-hand ferrules as in figure 4 were made with a perfect eye in both cases, tested, and compared. The left-hand ferrule clearly showed an efficiency of about 5 per cent more than the right-hand ferrule. In testing the latter the free end of the wire slipped in every case.

Figure 5.

In figure 5 an effort was made so secure the free end of the wire against slipping when strain was applied to the stay by wrapping this end around the main stay wire. Tests on this construction showed an average efficiency of 72 per cent, fracture taking place at "B."

Figure 6.

Another method of securing the loose end consisted of tying the end down on the ferrule with fine annealed wire as shown in figure 6. Tests made on this construction showed an average efficiency of 70 per cent, fracture taking place at "A."

CONCLUSIONS BASED ON ABOVE TESTS.

Observations made during tests of terminals 5 and 6 showed clearly that the weak points of this construction existed at "B" and "A," respectively, and that it was necessary to increase the friction between the walls of ferrule and the wire of the stay under strain to increase efficiency. Reliable information at hand showed that the same con-

clusions had been aimed at by foreign engineers stationed in America and that they had solved the problem by soldering the spring ferrule terminal in the same manner that Americans had adopted with the flat wire terminal.

HORN'S IMPROVED TERMINAL CONNECTION.

In an effort to avoid the use of solder with its many objectionable features types of construction as shown in figures 7 to 15, inclusive, were originated and tested. In every case the spring ferrule with left-hand pitch was adopted. The loose end of wire was secured with a tie or simple wire loop or clip as shown. Numerous tests made at intervals throughout the entire series of tests with wires having strengths of 1,600, 1,800, and 2,300 pounds showed conclusively that there is no difference in efficiency of stays using wire of any of the above strengths.

Figure 7.

Figure 7 shows a wedge between the ferrule and free end of wire so placed that as strain is applied to the stay and the bend in the free end of wire drawn toward the ferrule the wedge is forced in and thus increases the friction between the wall of the ferrule and the main stay wire. Average efficiency secured, 82 per cent; range of efficiency, 80 to 84 per cent. Fracture at "A" in ferrule.

Figure 8.

Figure 8 shows two wedges with a connecting yoke. The wedges enter on each side between the two wires and force them apart and against the wall of the ferrule as strain is applied. The wedges are forced in by pressure on the connecting yoke which passes under the bend of the free end of the wire as this free end is drawn into the ferrule under strain. Average efficiency of terminal in test equals 80 per cent. Range of efficiency in tests made, 79 to 83 per cent. Fracture at "A."

Figure 9.

In construction of figure 9 two wedges were used as in figure 8, but the yoke was replaced by a washer with two holes in it encircling both wires of the stay. Pressure on the wedges was supposed to be secured under strain by the drawing in of the loose end under strain. This result was not realized as the washer became locked on the main wire and broke the loose end at "D." Efficiency secured was only 70 per cent; range, 60 to 75 per cent.

Figure 10.

In figure 10 two wedges were used as in figure 8 and figure 9. The free end of the wire was wrapped around the main stay wire and pushed in the wedge as initial slippage occurred. Average efficiency, 84 per cent; range, 75 to 87 per cent. Fracture at "A" in ferrule.

Figure 11.

Figure 11 shows a double eye with no wedge. Standard straight ferrule with free end tied. This type of eye could only be used on stays when turnbuckles or hooks to be attached had open eye. Average efficiency in test, 80 per cent; range, 74 to 82 per cent. Fracture at "A."

Figure 12.

Figure 12 again shows a double eye in stay with a single wedge between wires on the eye end of the ferrule. As ferrule is drawn down against shoulders "A" and "B" the wedge is forced in. This increases friction of wires against ferrule at "A" and "B," but not at "D" and "E." Average efficiency, 85 per cent; range, 80 to 87 per cent. Fracture at "A."

Figure 13.

Figure 13 shows a construction consisting of a double eye in stay, a single wedge under the eye, and an oval spring wire ferrule tapered at the same angle as the wedge. In this case the pressure of the wedge forces both wires throughout the entire length of the ferrule against the walls of the ferrule and this increases friction on the ferrule uniformly as the strain increases on the stay and reduces the strain at the weak points "A" and "B" proportionately. Fracture always took place at "E." Average efficiency, 94 per cent; range, 92 to 95 per cent.

In figure 13 we have the most efficient terminal tested. It has none of the objections of a soldered terminal. It is simple, parts are inexpensive, strong, and few in number. It is an ideal terminal for emergency use in the field.

Figures 14 and 15.

Figures 14 and 15 show modifications of this type to overcome any objections which might be raised to the double eye. The wedge and a substantial thimble are combined in one piece. To secure more points of contact, and consequently greater friction, and also for greater flexibility, the taper ferrule is made of finer wires and with more convolutions. The wedge thimble may be open or closed, as desired. Fracture took place at "E." Average efficiency, 94 per cent; range, 92 to 96 per cent.

Summary of tests for efficiency.

Terminal.	Average efficiency.	Range of efficiency.	Points of fracture.	Remarks.
	Per cent.	*Per cent.*		
1	80	60–90	"A" or "B"	American, soldered.
2	65	60–75	"A" or slipped.	Foreign, proper eye.
3	62	60–65	Slipped	Foreign, improper eye.
4	60	59–61	...do	Right-hand ferrule.
5	72	65–75	"B"	End wrapped around stay.
6	70	68–78	"A"	End tied to ferrule.
7	82	80–84	"A"	Wedge under hook.
8	80	79–83	"A"	Two wedges with yoke.
9	70	60–75	"D"	Two wedges with washer.
10	84	75–87	"A"	Two wedges end wrapped.
11	80	74–82	"A"	Double eye, no wedge.
12	85	80–87	"A"	Double eye, 1 wedge.
13	94	92–95	"E"	Tapered ferrule, double eye, wedge.
14–15	94	92–96	"E"	Thimble wedge T. F. single eye.

NOTE.—These tests were made with wire having a diameter of 0.102 inch and a strength of 1,600, 1,800, and 2,300 pounds. No difference in efficiency of stay was found by using wire of any of these strengths.

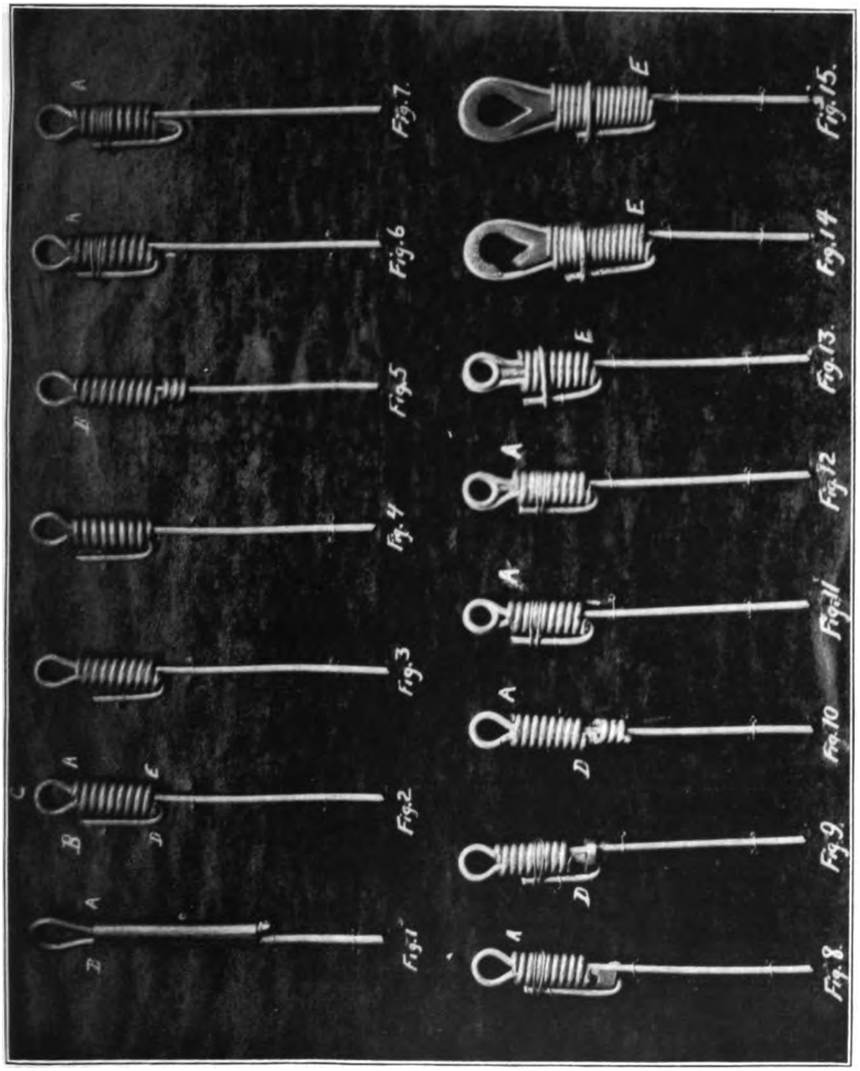


Fig. 1
Fig. 2
Fig. 3
Fig. 4
Fig. 5
Fig. 6
Fig. 7
Fig. 8
Fig. 9
Fig. 10
Fig. 11
Fig. 12
Fig. 13
Fig. 14
Fig. 15

PLATE No. 1.

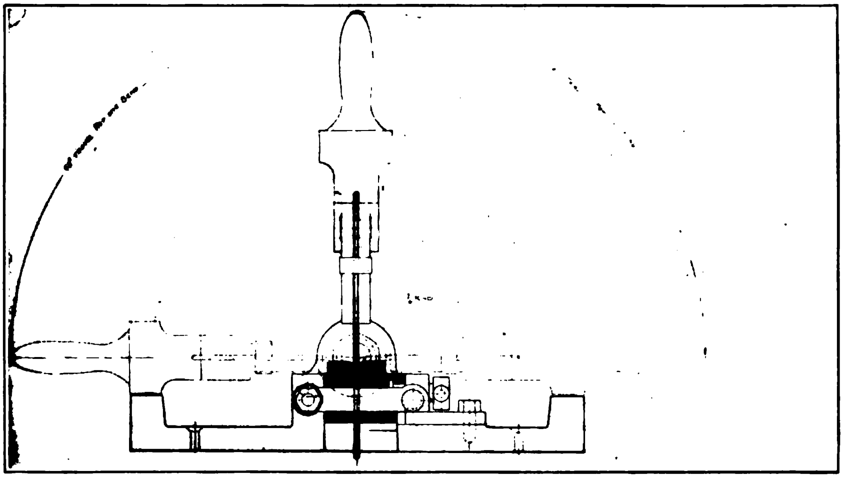


PLATE No. 2.

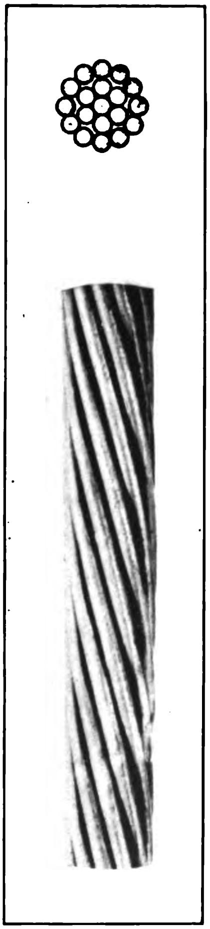


PLATE No. 3.

STANDARD WIRE FOR STAYS FOR AEROPLANES.

The original object in the manufacture of this material was the securing of the wire as strong as possible in order to reduce the weight as much as possible. This resulted eventually in the manufacture of a wire so hard and strong that difficulty was experienced in forming the eye and bend over the ferrule without breaking the wire. The result of this was a lack of confidence in high-strength wire, and in some cases the reaction extended to the use of a wire which could properly be classed as a soft wire. The process of soldering terminals on wire stays undoubtedly helped to a great extent in building up this prejudice. Nevertheless it is still true, as at first, that a strong wire which is serviceable permits the possibility of reducing weight and is therefore desirable. The great number of tests on wire and stays, which were necessary to determine the properties of different types of terminals as described above, afforded a very excellent opportunity to note conclusively the effect of using various grades and strengths of wire. We determined that it was all important that the wire should be tough and ductile as well as strong. All bends should be made without danger of fracture. In addition to requirement for tensile strength, we found it necessary to recommend requirements for torsion and bend. As the per cent efficiency of the stay due to loss of strength at terminal is as great with a strong wire as with a weaker wire, as was clearly demonstrated in our tests, it followed conclusively that as high a strength as can be secured commercially under the conditions of torsion and bend test required was desirable. The following specification is therefore recommended as representing suitable high-grade material for the purpose.

Standard aviator wire (tinned).

Diameter (inches).	American gauge (Brown & Sharpe).	Nearest fraction of inch.	Minimum breaking strain.	Minimum torsion in 6 inches.	Minimum number of bends through 90° over $\frac{1}{16}$ inch radius of jaws.	Weight in pounds per 100 feet.
0.204	4	$\frac{13}{64}$	6,700	9	4	11.15
.182	5	$\frac{3}{16}$	5,500	10	4	8.84
.162	6	$\frac{5}{32}$	4,500	11	5	7.01
.144	7	$\frac{9}{64}$	3,700	12	6	5.56
.128	8	$\frac{1}{8}$	3,000	14	8	4.40
.114	9	$\frac{7}{64}$	2,500	16	9	3.50
.102	10	....	2,000	18	11	2.77
.092	11	$\frac{3}{32}$	1,620	21	14	2.20
.081	12	$\frac{5}{64}$	1,300	24	17	1.744
.072	13	....	1,040	27	21	1.383
.064	14	$\frac{1}{16}$	830	31	25	1.097
.057	15	....	660	34	29	.870
.051	16	....	540	39	34	.690
.045	17	$\frac{3}{64}$	425	44	42	.547
.040	18	....	340	49	52	.434
.036	19	....	280	55	70	.344
.032	20	$\frac{1}{32}$	225	61	85	.273
.028	21	....	175	70	105	.216

PLATE NO. 2.

Breaking strain.—Test sample should be at least 15 inches long, free from nicks or bends. It should measure 10 inches in the clear between the jaws of a standard testing machine. Load should be applied uniformly at a speed not exceeding 1 inch per minute.

Torsion.—Test sample should be gripped by two vises 6 inches apart. One vise is turned uniformly at a speed not exceeding 60 revolutions per minute. On the large size of wire this speed should be reduced sufficiently to avoid undue heating of the wire. The vise which is not turned should have free lateral movement in either direction.

Bend test.—Wire for bending test should be a straight piece. One end is clamped between jaws having their upper edges rounded to 3/16-inch radius. The free end of the wire is held loosely between two guides and bent 90° over one jaw. This is counted one bend. On raising to vertical position the count is two bends. Wire is bent to the other side and so forth, alternating to fracture, each 90° bend counting one.

Diameter of strand.	Breaking strength of strand.	Approximate weight per 100 feet.
$\frac{5}{16}$	12,500	20.65
$\frac{1}{4}$	8,000	13.50
$\frac{7}{32}$	6,100	10.00
$\frac{3}{16}$	4,600	7.70
$\frac{5}{32}$	3,200	5.50
$\frac{1}{8}$	2,100	3.50
$\frac{7}{64}$	1,600	2.60
$\frac{3}{32}$	1,100	1.75
$\frac{5}{64}$	780	1.21
$\frac{1}{16}$	500	.78
$\frac{1}{32}$ 7 wire	185	.30

PLATE NO. 3.

ROEBLING 19-WIRE GALVANIZED AVIATOR STRAND.

Roebling galvanized aviator strand consists of 19 fine wires of great strength stranded together. On account of its small size the $\frac{1}{32}$-inch diameter strand is made of seven wires. This strand is not very flexible and is used for stays. This strand is approximately one and one-third times as elastic as a solid wire of the same material.

Thimble spliced in each end.

Diameter of strand.	Breaking strength of strand.	Breaking strength of stay.	Efficiency (per cent).	Approximate weight per 100 feet.
$\frac{1}{4}$	8,000	7,200	90.0	13.50
$\frac{7}{32}$	6,100	5,500	90.0	10.00
$\frac{3}{16}$	4,600	4,180	91.0	7.70
$\frac{5}{32}$	3,200	3,000	93.7	5.50
$\frac{1}{8}$	2,100	2,060	98.2	3.50
$\frac{7}{64}$	1,600	1,570	98.1	2.60
$\frac{3}{32}$	1,100	1,100	100	1.75
$\frac{5}{64}$	780	780	100	1.21
$\frac{1}{16}$	500	500	100	0.78

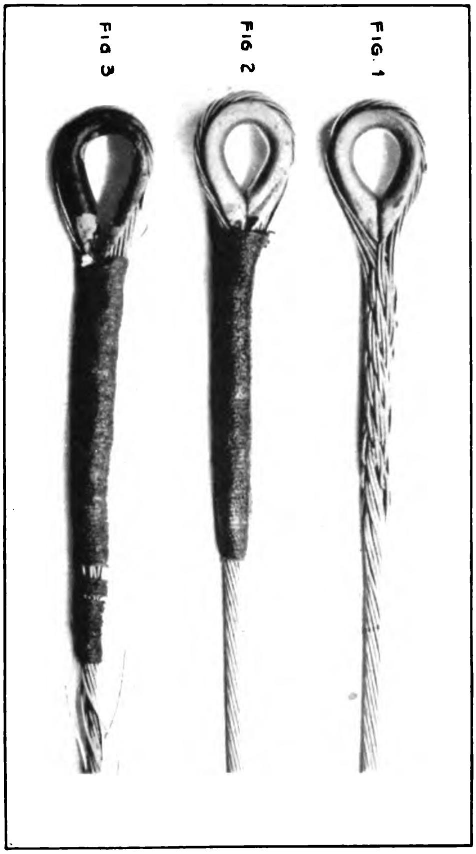


PLATE No. 4.

PLATE No. 5.

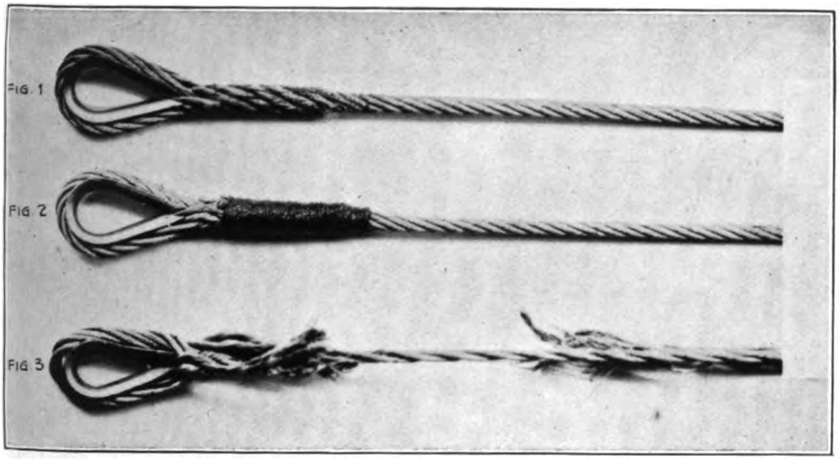


PLATE NO. 6.

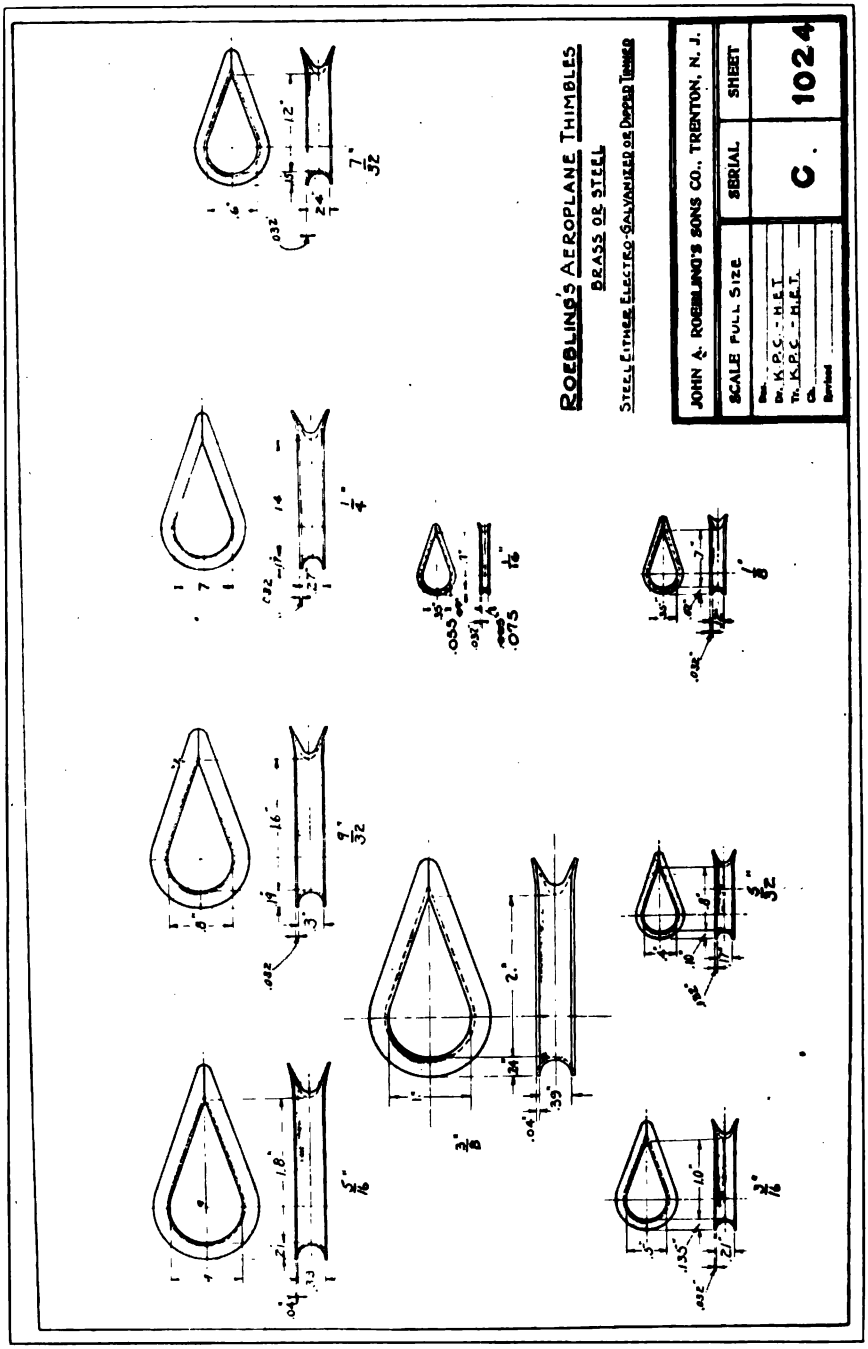

ROEBLING'S AEROPLANE THIMBLES
BRASS OR STEEL
STEEL EITHER ELECTRO-GALVANIZED OR DIPPED TINNED
JOHN A. ROEBLING'S SONS CO., TRENTON, N. J.
SCALE FULL SIZE
SERIAL
SHEET
C
1024

PLATE No. 7.

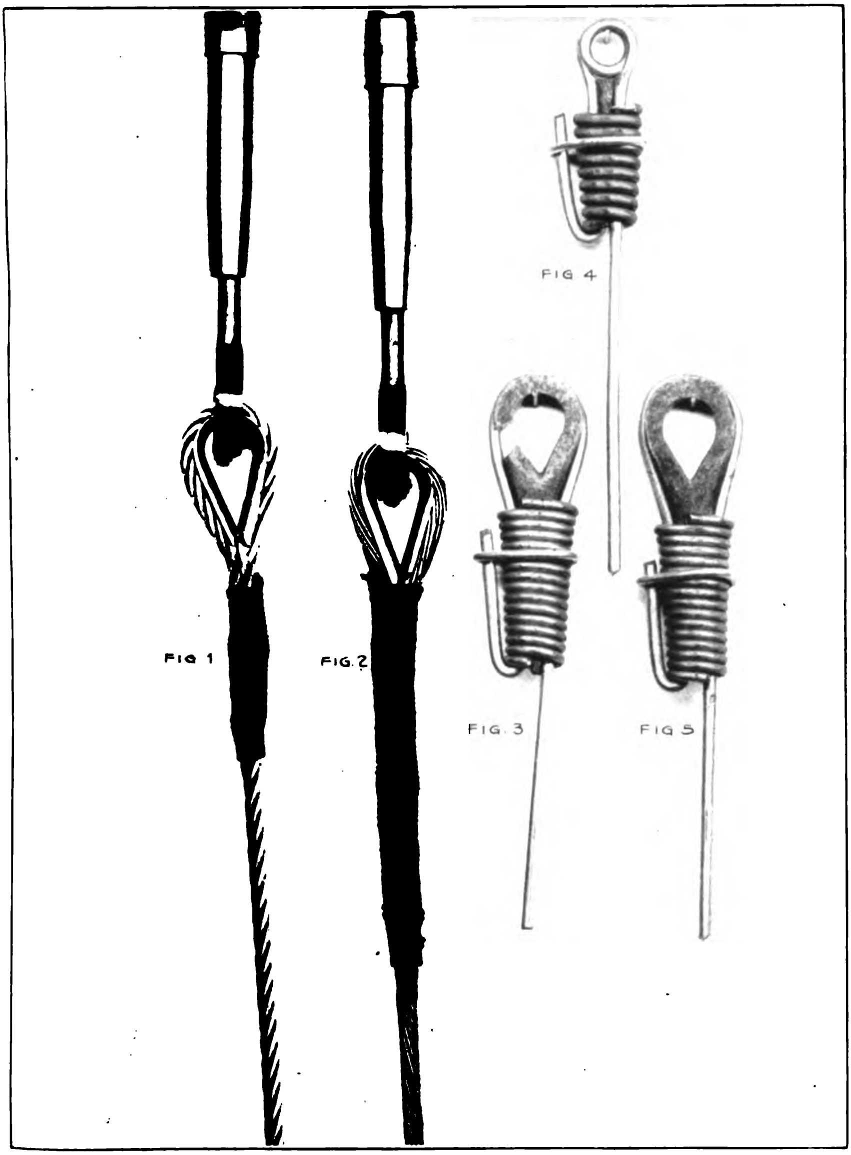


PLATE No. 8.

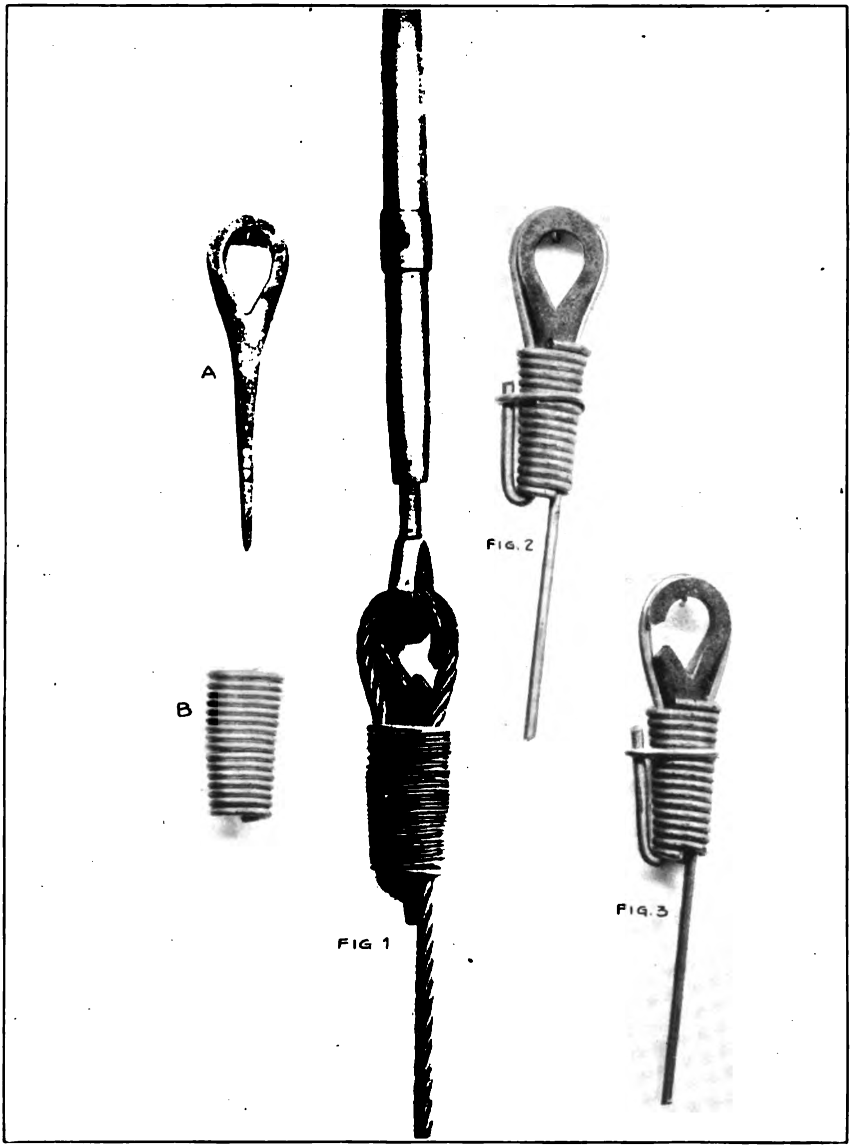


PLATE No. 9.

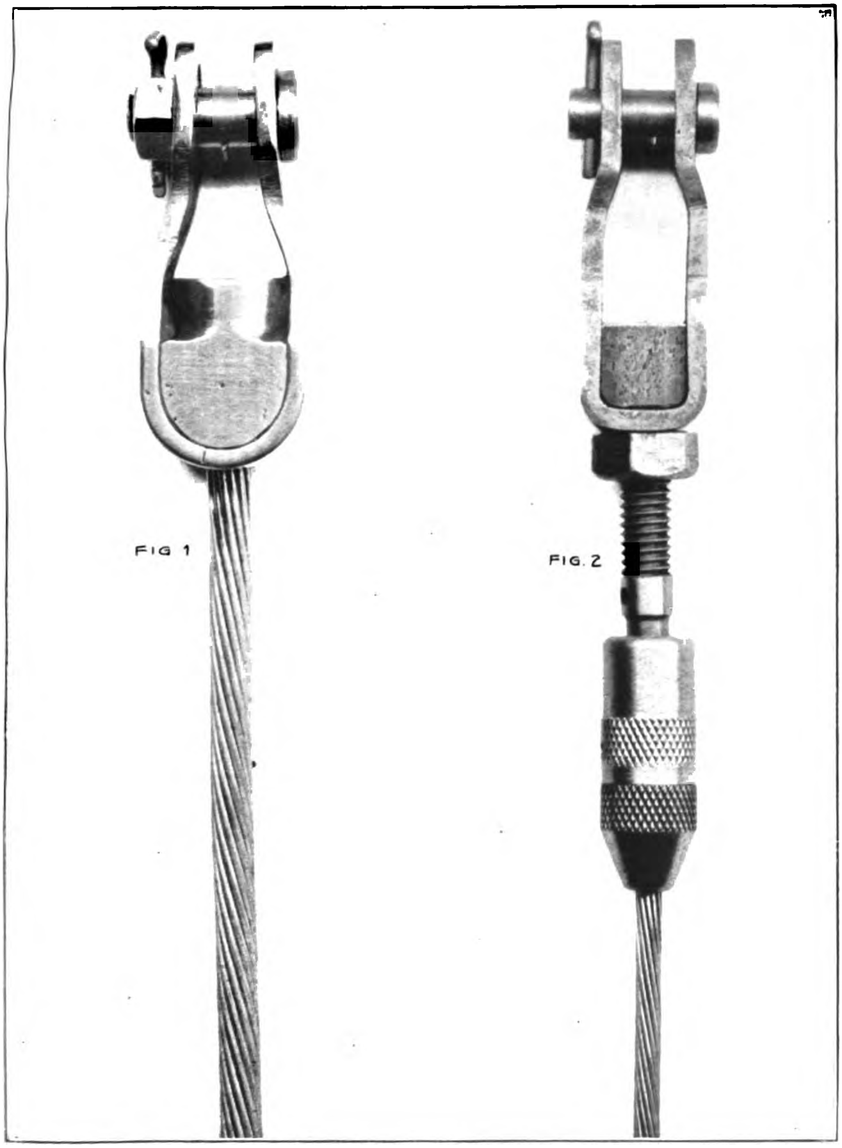


PLATE No. 10.

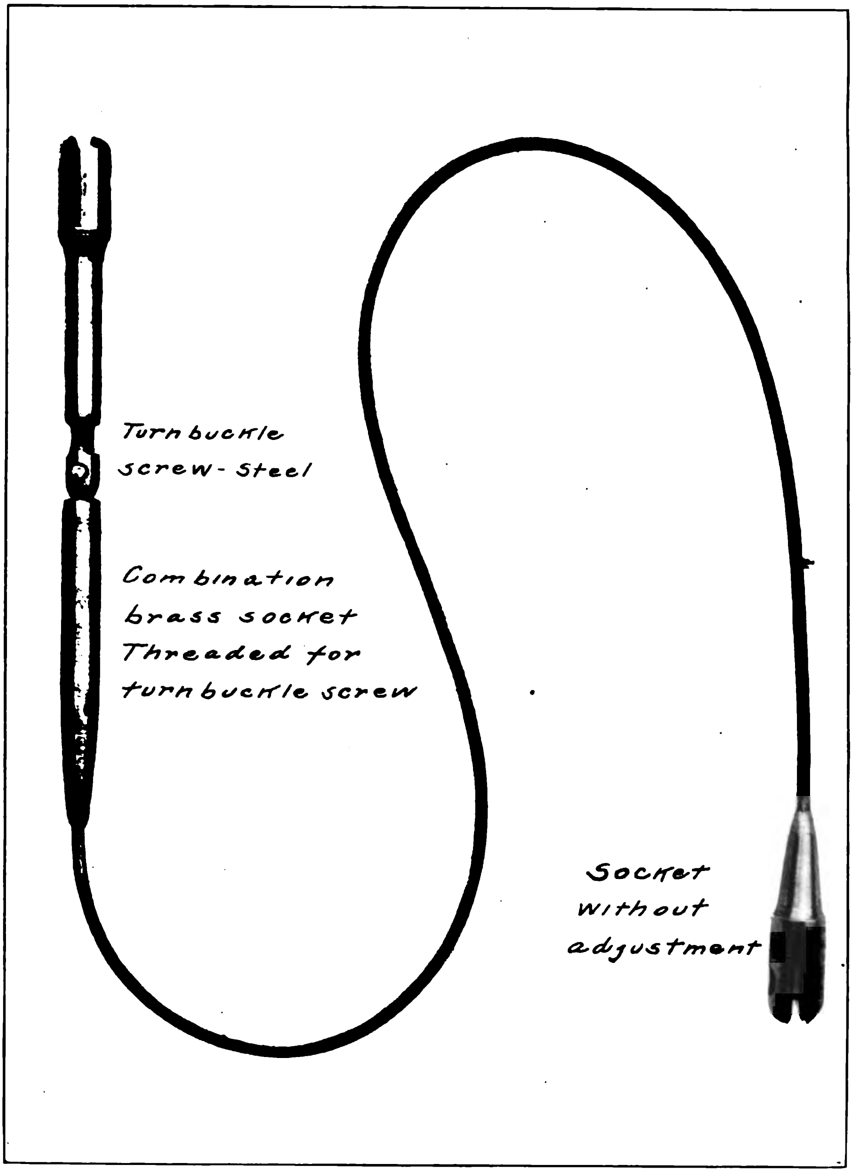

Turn buckle
screw - Steel
Combination
brass socket
Threaded for
turn buckle screw
Socket
without
adjustment

PLATE No. 10 A.

PLATE NO. 4.

ROEBLING 19-WIRE GALVANIZED AVIATOR STRAND.

Figure No. 1 shows thimble spliced in 19-wire galvanized aviator strand.

Figure No. 2 shows the splice after the serving is applied.

Figure No. 3 shows the broken wires after the stay had been tested to destruction in the testing machine. It will be noted there are four broken wires. This break always occurs at the last tuck in the splice and never around the thimble.

Diameter of cord.	Breaking strength cord (pounds).	Approximate weight per 100 feet.
$\frac{1}{8}$	2,000	2.88
$\frac{5}{32}$	2,800	4.44
$\frac{3}{16}$	4,200	6.47
$\frac{7}{32}$	5,600	9.50
$\frac{1}{4}$	7,000	12.00
$\frac{9}{32}$	8,000	14.56
$\frac{5}{16}$	9,800	17.71
$\frac{11}{32}$	12,500	22.53
$\frac{3}{8}$	14,400	26.45

PLATE NO. 5.

ROEBLING 7 BY 19, TINNED AVIATOR CORD.

Roebling tinned aviator cord is composed of 7 strands of 19 wires each. This wire is made from the highest grade of steel and given a heavy plating of tin. It is used principally for stays on foreign machines. This cord is approximately one and three-quarter times as elastic as a solid wire of the same material.

Thimble spliced in each end.

Diameter of cord.	Breaking strength of cord.	Breaking strength of stay.	Efficiency.	Approximate weight per 100 feet.
$\frac{1}{8}$	2,000	1,600	Average of 54 tests 83.6 per cent.	2.88
$\frac{5}{32}$	2,800	2,300		4.44
$\frac{3}{16}$	4,200	3,500		6.47
$\frac{7}{32}$	5,600	4,700		9.50
$\frac{1}{4}$	7,000	6,000		12.00
$\frac{9}{32}$	8,000	6,800		14.56
$\frac{5}{16}$	9,800	8,200		17.71
$\frac{11}{32}$	12,500	10,400		22.53
$\frac{3}{8}$	14,400	12,000		26.45

PLATE NO. 6.

ROEBLING 7 BY 19, TINNED AVIATOR CORD.

Figure No. 1 shows thimble spliced in 7 by 19 tinned aviator cord.

Figure No. 2 shows the splice after the serving is applied.

Figure No. 3 shows the result of a test to destruction in the testing machine. Five strands have been broken at the last tuck in the splice. In all the 54 tests the stay failed at this point and never around the thimble.

PLATE NO. 7.

THIMBLES.

The eye splice in strand and cord should be protected by means of either steel or brass thimble.

The brass thimble can be used for 19-wire strand for diameters of 1/8 inch and smaller. For larger diameters use steel thimbles.

For the 7 by 19 cord use brass thimble for 3/16 inch diameters and smaller, and steel thimbles for larger diameters.

PLATE NO. 8.

SHOP CONNECTIONS.

Figure No. 1.—Based upon tests, believe the eye splice for the 7 by 19 cord is the most satisfactory for all sizes, including ½ inch diameter, unless higher efficiency is required, in which case a socket attachment can be used for the larger diameters.

Figure No. 2.—The eye splice is very satisfactory for 19-wire strand for diameters not exceeding $\frac{5}{16}$ inch. For larger diameters a socket attachment is necessary to get high efficiency.

Figures Nos. 3, 4, and 5.—The tapered ferrule and wedge attachment gives maximum efficiency, and we believe can be used to great advantage for single-wire stays.

PLATE NO. 9.

FIELD CONNECTIONS.

The repairing of stays in the field has been given careful consideration, and *Figure No. 1* on plate No. 9 shows a very simple and efficient device for attachment of either 19-wire strand or 7 by 19 cord. The efficiency is 90 per cent.

The wedge "A" and ferrule "B" are the two important members of the connections. After the strand or cord is placed on wedge and through ferrule, the end of same is bent backward on ferrule and then served with wire.

Figures Nos. 2 and 3 show the same type of connection for wire attachment. The efficiency is 94 per cent.

PLATE NO. 10 AND PLATE NO. 10A.

SOCKET ATTACHMENT.

We believe the socket attachment can be used to advantage in connection with 19-wire strand, especially on the larger diameters.

The efficiency is nearly 100 per cent and the connection is positive and safe.

We find it necessary to use pure zinc for attachment of galvanized strand.

Plate No. 10 shows two types of sockets—

Figure No. 1 not furnished with adjustment and *Figure No. 2* having adjustment.

Plate No. 10A shows the sockets used by the Glenn L. Martin Co., and it is stated their efficiency is 100 per cent.

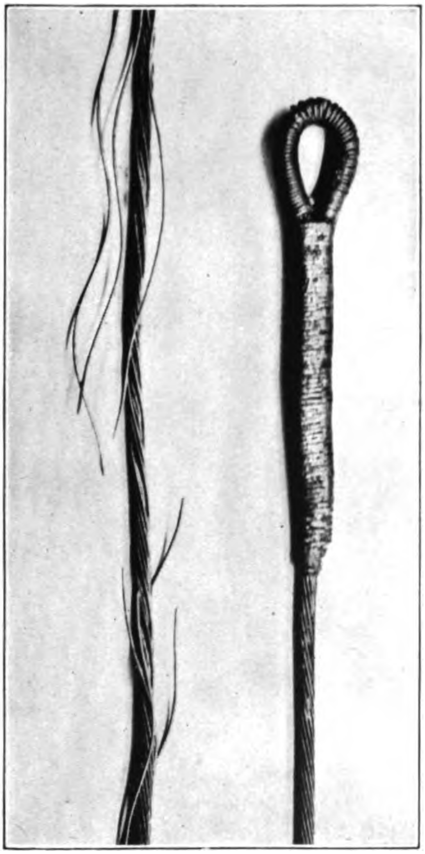


PLATE No. 11.

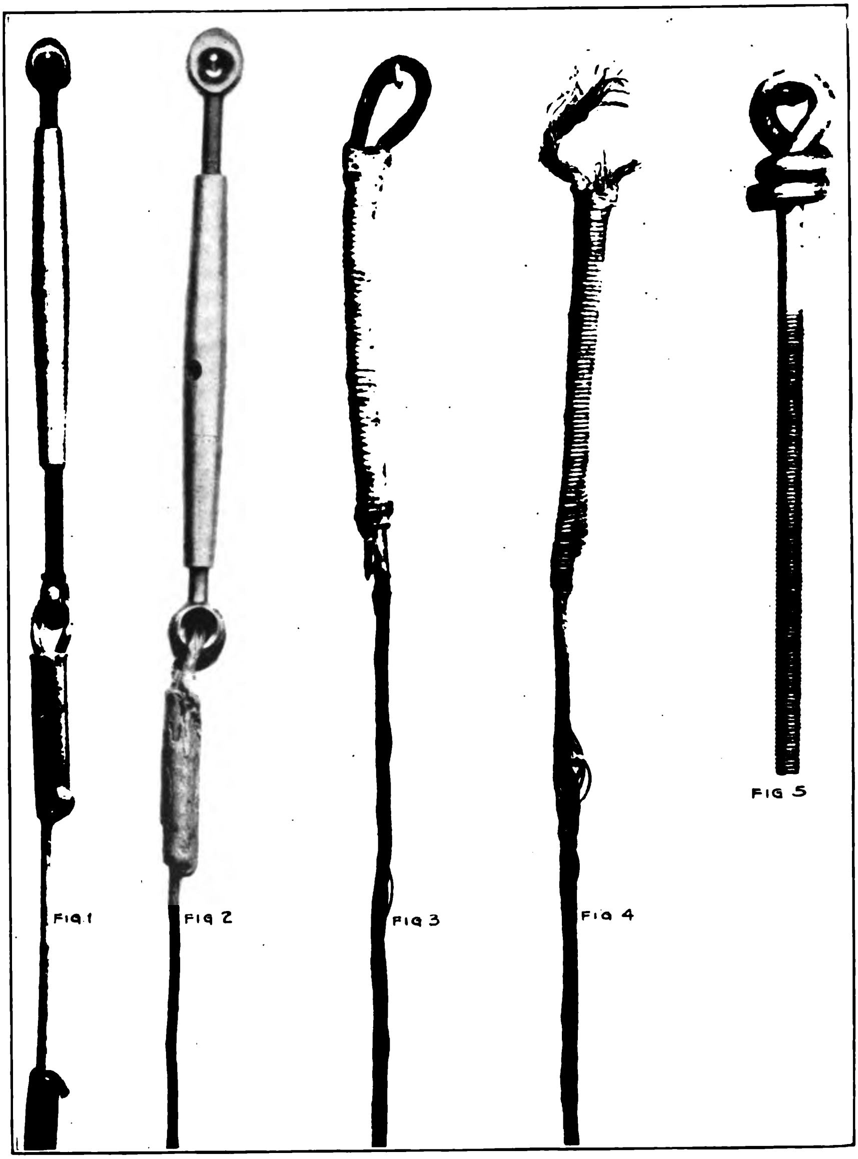


PLATE No. 12.

PLATE NO. 13.

PLATE No. 14.

PLATE NO. 11.

ROEBLING 19-WIRE GALVANIZED AVIATOR STRAND.

Figure No. 1 shows a 19-wire galvanized aviator strand with end looped and soldered.

Figure No. 2 shows the result of test to destruction in the testing machine. It will be noted that the break of the seven wires occurs at the center of the stay and never at the ends. In the series of tests made this connection showed an efficiency of 100 per cent.

Special attention is called to the protective serving of the loop. In case this is not done a thimble must be used. The principal objections to this connection are the use of acid and solder.

Ends looped and soldered.

Diameter of strand.	Breaking strength of strand.	Breaking strength of stay.	Efficiency (per cent).	Length of lap.	Serving of lap.	Approximate weight per 100 feet.
$\frac{1}{4}$	8,000	8,000	100	20 times diameter of strand.	Diameter of serving wire = $\frac{1}{4}$ diameter of strand.	13.50
$\frac{7}{32}$	6,100	6,100	100			10.00
$\frac{3}{16}$	4,600	4,600	100			7.70
$\frac{5}{32}$	3,200	3,200	100			5.50
$\frac{1}{8}$	2,100	2,100	100			3.50
$\frac{7}{64}$	1,600	1,600	100			2.60
$\frac{3}{32}$	1,100	1,100	100			1.75
$\frac{5}{64}$	780	780	100			1.21
$\frac{1}{16}$	500	500	100			.78

PLATE NO. 12.

EXAMPLES OF PRESENT PRACTICE.

No. 1 shows the solid wire, using a copper tube as a ferrule, and if attached properly will give efficiency of 75 to 80 per cent.

No. 2 shows a 19-wire strand attachment, using a copper tube as a ferrule and bending the strand back and soldering both inside and outside of ferrule. Note that the strand is not protected where it bears on turnbuckle and the strand fails here. The efficiency is low.

No. 3 shows a 19-wire strand attachment where the strand is looped, served, and then soldered. Note the wire displacement in loop.

No. 4 was taken from a wrecked aeroplane and shows point of failure in loop, due to want of protection at this point.

No. 5 shows form of eye for solid wire, which makes it necessary to use medium steel to allow manipulation.

Diameter of cord.	Breaking strength of cord.	Approximate weight per 100 feet.
$\frac{5}{16}$	7,900	15.00
$\frac{1}{4}$	5,000	9.50
$\frac{7}{32}$	4,000	7.43
$\frac{3}{16}$	2,750	5.30
$\frac{5}{32}$	2,200	4.20
$\frac{1}{8}$	1,150	2.20
$\frac{7}{64}$	830	1.50
$\frac{3}{32}$	780	1.30
$\frac{5}{64}$	480	.83
$\frac{1}{16}$	400	.73

PLATE NO. 13.

ROEBLING EXTRA FLEXIBLE AVIATOR CORD 6 BY 7 COTTON CENTER.

Roebling extra flexible aviator cord is composed of six strands of seven galvanized wires each and a cotton center. On account of its flexibility this cord is used for steering gear and controls. This cord is approximately two and one-quarter times as elastic as a solid wire.

Diameter of cord.	Breaking strength of cord.	Approximate weight per 100 feet.
$\frac{5}{16}$	9,200	16.70
$\frac{1}{4}$	5,800	10.50
$\frac{7}{32}$	4,600	8.30
$\frac{3}{16}$	3,200	5.80
$\frac{5}{32}$	2,600	4.67
$\frac{1}{8}$	1,350	2.45
$\frac{7}{64}$	970	1.75
$\frac{3}{32}$	920	1.45
$\frac{5}{64}$	550	.93
$\frac{1}{16}$	485	.81

PLATE NO. 14.

ROEBLING FLEXIBLE AVIATOR CORD 6 BY 7 WIRE CENTER.

Roebling flexible aviator cord is made with seven strands of seven galvanized wire each. This cord is not as flexible as the cotton center cord and is approximately one and three-quarters times as elastic as a solid wire.

PROTECTIVE COATINGS ON STEEL WIRES.

NONFERROUS METALS—ALLOY STEELS.

We manufacture wire and cable in nonferrous metals such as monel metal, german silver, phosphor bronze, aluminum bronze, silicon bronze, brass, copper, etc., but we do not believe that any of these metals will ever prove commercially practicable for the purpose of aeroplane stays or cables. "Maximum strength with minimum weight" appears to be too all-important. In none of these can extreme reliability with high elasticity be so well secured as with steel when it is well protected from mechanical injury and corrosion. For exceptional purposes, the nonmagnetic properties of these metals may outweigh their lack of strength and durability in fatigue, making their use imperative, but in the final design the amount thus used will undoubtedly be the least possible amount permissible under the circumstances. For construction of this kind we would not recommend, without many qualifications, a natural alloy such as monel metal. This material appears to possess excellent noncorrosion properties when used in a relatively large mass, as in a propeller, but there appears to be considerable doubt as to its absolute reliability in uniformly resisting corrosion when rolled into very thin sheets or drawn into wire. To a lesser degree, a lack of confidence must exist in such manufactured alloys as brass, german silver, or bronzes containing relatively large proportions of two or more elementary metals. "Phosphor bronze," "silicon bronze," "aluminum bronze," or similar alloys containing a relatively high per cent of one element (copper)

only, are more "fool-proof" and consequently more reliable and desirable.

An attempt to give the elastic limit and tensile strength of each size of wire, strand, and cable used in aeroplane construction, if same were made of all the nonferrous metals mentioned above, would involve the publication of quite an extensive report. Confining ourselves to the most suitable of these metals or alloys, phosphor bronze, aluminum bronze, etc., it is a safe and reliable rule to assume that the ultimate strength of such wire or cable or stay will be 50 per cent of the ultimate strength of the extra high-strength steel listed by us for standard aeroplane use. The elastic limit for nonferrous metals could not safely be assumed at more than 50 per cent of the ultimate breaking strain.

The use of vanadium, titanium, ana other special deoxidizers or cleansers in the manufacture of steel has undoubtedly resulted in very much improving homogeneity and density of structure in cast, forged, and other hot-worked masses of the metal especially in the harder alloyed varieties. It is not so certain, however, that the use of these metals has proven necessary or even desirable in making steels of the higher grade for wire manufacture where the enormous amount of cold working and exact heat treatment absolutely inherent to the process of wire manufacture produces eventually a structure finer and more homogeneous than has ever been possible by any other method. The increased resistance to corrosion which the special steels, referred to above, afford, because of their density and uniformity, is more than duplicated by any drawn high-grade wire of the ordinary carbon steels of sufficient degree of manufacture.

Vanadium steels and other steels of their kind have not as yet become established as desirable wire steels. Although strongly urged upon the industry and tried time and again, they have not demonstrated their superiority.

Carefully made high-grade carbon steel affords to-day the most reliable and flexible material for wire, cable, and stays, possessing the "greatest strength for the least weight" known in the wire industry. We know its advantages and we know its disadvantages. The fact that the mechanical properties of steel wire and cable are seriously affected by corrosion is so well known that it must be guarded against. As the damage done is a function of time as well as intensity of chemical or electro-chemical action on the unprotected steel, we have investigated the question of retarding corrosion in the steel itself to as great a degree as possible. We have found that pure iron retards corrosion to a greater degree than the more impure steel—but we have also found that in highly extenuated filaments of these two metals, as in wire, the difference in rate of corrosion is practically negligible, especially when the total life of the wire protected by an external coating such as galvanizing is taken into consideration. We have found the use of special deoxidizers and cleansers questionable and have not adopted them.

The use of protective coatings on steel wire or cable is a very broad subject. Hot galvanized unwiped wire is undoubtedly the best protected wire for the purpose. Very hard wires and very fine sizes of hard wire are likely to become brittle at the temperature of hot galvanizing, and the next best coating available is, therefore, a tin coating. Both of these metal coatings should be further protected

by frequent applications of paint. As a protection to the galvanizing, a coat of red-lead paint should be applied after the stay is assembled and the red lead protected by a coat of graphite paint.

The care with which inspections are made from time to time and the efficient maintenance of the paint on the wires really determines the life of the combination. This has been proven absolutely by the very extensive use and treatment of galvanized steel on board ship for many years.

Nickel plating is out of the question for wires to be bent or twisted into cable. Furthermore, nickel is absolutely injurious where the initial purely chemical action on the intact nickel surface ceases and electro-chemical action between steel and nickel begins at such spots when steel is exposed.

We believe, therefore, that tinning and galvanizing are to-day the most satisfactory coatings for steel wire that can be employed. They do not actually represent the final and efficient protection which is necessary in aeroplane construction, as this is secured by the repeated application of paint. These coatings are, however, an efficient guard against corrosion preliminary to service conditions in the plane and also serve to prevent corrosion and consequent damage to the steel cables and stays in service when the paint may have been accidentally rubbed off.

RECAPITULATION.

WIRE STAYS.

As shown by tests, the terminal fastening, figures 13 and 14, on plate No. 1, are efficient, simple, and readily attached, and we believe solve the question.

For shop attachment figure 13 or 14 would be used in connection with shackles and clevises, and for attaching to turnbuckle eye or other closed eyes use figure 15.

For field attachment use either figure 14 or 15.

Plates No. 8 and No. 9 also show these terminal connections.

WIRE SPECIFICATIONS FOR STAY WIRES.

Plate No. 2 and pages 10 and 11 of this report give specifications for wire having the highest possible strength, together with the necessary ductility for manipulation, and is the result of many years of experimenting in cooperation with engineers and manufacturers of aeroplanes.

19-wire strand stays.

Plates No. 3 and No. 4 give the strength of this strand, also the strength of same as stays using the thimble eye splice for terminal connection, and judging from tests as given, this connection is efficient, neat in appearance, and reliable.

Plate No. 11 gives table of stay strength when the ends of the strand are looped and soldered. The efficiency of this connection is a maximum, but the use of acid and solder are objectionable, and we believe the thimble eye splice with slightly lower efficiency is preferable.

We understand ¼-inch diameter strand is the largest diameter used, but judging from present development larger diameter will be required and it will be found that the thimble eye splice, also the ends looped and soldered, will not give the same efficiency as the diameter increases and we believe the use of sockets for ⅜-inch diameter and larger may be desirable.

Plate No. 10 shows two types of sockets.

For making terminal connection of strand in the field, we believe the arrangement shown on plate No. 9 is best, as it gives 90 per cent efficiency and is readily attached by the average man and does not require the use of acid, solder, or blow torch.

7 by 19 cord stays.

Plates No. 5 and No. 6 show the 7 by 19 rope which is flexible, elastic, and lends itself readily to thimble splice, giving very uniform efficiency and has the advantage of higher efficiency for diameters between ⅜ and ½ inch.

We have determined by tests that the socket connection alone gives higher efficiency than the thimble eye splice on 7 by 19 cord, but as a general proposition believe the thimble eye splice is entirely suitable for stay construction.

For a field connection plate No. 9 shows the most suitable type.

CONCLUSIONS.

The tests as given show that it is possible to furnish efficient terminal connections for wire, strand, and 7 by 19 cord, and eliminate the use of acid, solder, and blow torch, and this report as a basis will allow a more thorough investigation on similar lines.

We are unable to determine from aeroplane manufacturers why it is necessary to use the solid wire, 19-wire strand, and the 7 by 19 cord for stays. It is self-evident that the wire stay is less elastic than the 19-wire strand, also that the strand is less elastic than the 7 by 19 cord, also the strength varies considerably, as can be determined by comparison of tables as given before, and to allow a quick comparison we give below:

Comparison of stay strength.

Material.	Diameter.	Strength of material.	Strength of stay.
	Inch.	*Pounds.*	*Pounds.*
Wire	$\frac{3}{16}$	5,500	5,100
Strand	$\frac{3}{16}$	4,600	4,100
7 by 19 cord	$\frac{3}{16}$	4,200	3,500

American practice covers both the wire and 19-wire strand stay and foreign practice requires the use of 7 by 19 cord for stay.

The table above shows how much more efficient the wire and strand stays are for the same diameter and therefore we are led to believe there are other considerations just as important as strength, such as the elastic stretch of stays, flexibility and fatigue values of material

which may be governed by the construction of stay, and we believe these points should be investigated under field conditions as well as laboratory tests.

We hoped to give this report stress-strain diagram for the solid wire, 19-wire strand, also 7 by 19 cord, so that the modulus of elasticity could be determined for any desired load and elastic stretch of stay calculated for comparison. We were unable to complete our tests in time, and therefore if you decide this is of value we will be pleased to submit these diagrams and any other data developed. If vibration of stays is a factor, the relative fatigue value of the three constructions would give interesting data.

Respectfully submitted.

JOHN A. ROEBLING'S SONS CO.,
By C. C. SUNDERLAND, *Engineer*.

(Investigations under direction of C. C. Sunderland, H. J. Horn, and D. Green.)

REPORT No. 4.

PRELIMINARY REPORT ON THE PROBLEM OF THE ATMOSPHERE IN RELATION TO AERONAUTICS.

By PROF. CHARLES F. MARVIN.

REPORT No. 4.

PRELIMINARY REPORT ON THE PROBLEM OF THE ATMOSPHERE IN RELATION TO AERONAUTICS.

UNITED STATES WEATHER BUREAU,
Washington, D. C., November 9, 1915.

GENTLEMEN: The particular work comprising the subject of this report has been undertaken pursuant to an allotment by Dr. Charles D. Walcott, Secretary of the Smithsonian Institution, of $2,500, made available through the Secretary of Agriculture to the Chief of the Weather Bureau. At the meeting of the executive committee held June 11, 1915, the chairman, Dr. Charles D. Walcott, was authorized to designate Charles F. Marvin, Chief of the Weather Bureau, as chairman of a subcommittee to investigate and report upon the problem of the atmosphere in relation to aeronautics. He was requested to select other members of the subcommittee, not to exceed four, and Profs. William J. Humphreys and William R. Blair, of the United States Weather Bureau, subsequently consented to act as members of the subcommittee.

At the meeting of the executive committee held August 5, 1915, a proposal of work to be undertaken was outlined by the chairman of the subcommittee on the atmosphere in relation to aeronautics, the substance of which is briefly quoted as follows:

The Weather Bureau is already in possession of an immense amount of data concerning atmospheric conditions, including wind movements at the earth's surface. This information is no doubt of distinct value to aeronautical operations, but it needs to be collated and put in form to meet the requirements of aviation. The bureau also has a considerable amount of determinations of atmospheric conditions in the free air. Most of these observations were made at Mount Weather, but others have been made at a few points in the West, such as Huron, S. Dak.; Fort Omaha, Nebr.; Avalon, Cal.; and a few aboard the Coast Guard cutter *Seneca*, during the past summer while this vessel was engaged on ice patrol off the Newfoundland coast. Portions of these data also are undoubtedly valuable to aviation, but it is quite apparent that but a small fraction of the material needed to meet the requirements of aeronautical work throughout the United States is available, and that therefore much additional observation work is necessary.

In considering the work that should be done along these lines, further cooperation is needed by the Weather Bureau with those actually engaged in aeronautical operations, and with this need in view Prof. Blair, a member of the subcommittee, has already been in conference with Mr. F. R. McCrary, acting director of naval aeronautics. It is proposed to utilize the fund made available by the Smithsonian Institution to undertake a careful compilation of the data already available in the Weather Bureau records, this compilation to be along lines that will make the data available to aviation; also that additional observations be undertaken to gain information concerning atmospheric conditions by means of pilot balloons, the position and motions of which are recorded by theodolites and such other apparatus as the work may require. It may be proper to state at this point that the Weather Bureau is already conducting aerial investigations of direct interest to meteorology, and that the new work herein proposed will be supplementary and in addition to the work the Weather Bureau is

already performing. Embarrassment has been experienced in the progress of this work since the European war on account of the inability to procure serviceable rubber balloons. A manufacturer in Ohio has undertaken to supply these, and has submitted a considerable number of samples and full-sized balloons. So far, however, the results have been almost a complete failure, on account of the seeming inability to secure the necessary strength and gas tightness at the seams. Work is still in progress, however, on the manufacture of the balloons, and we are hopeful of more favorable results in the future.

The following outline indicates approximately the subject matter of a meteorological character it is expected to include in the proposed publications:

ATMOSPHERIC CONDITIONS IN RELATION TO AERONAUTICS.

1. INTRODUCTION.—Brief presentation of a few fundamental principles and data relating to general atmospheric conditions and motions and forming a basis for the subsequent discussion of relations of temperature pressure and motions of the atmosphere.

CHAPTER I.—General meteorological and climatological data selected and classified with respect to its bearing on aeronautics. The data should show general surface conditions of weather, temperature, sunshine, rain, thunderstorms, humidity, and wind velocity and directions; also comprise as full information concerning average free-air conditions as the scanty data available permit.

CHAPTER II.—A discussion of particular and local atmospheric conditions as affecting aviation.

CHAPTER III.—General presentation of free-air conditions arranged with relation to surface conditions.

CHAPTER IV.—Instruments with special reference to aviation.

CHAPTER V.—Miscellaneous useful material not otherwise included.

APPENDIX.—Formulæ and practical tables.

The practical closing of European markets for certain instrumental supplies has prevented procuring recording theodolites of special construction needed in studying atmospheric motions by means of pilot and sounding balloons. A type of instrument of this kind has been designed and efforts are being made to secure the manufacture in the United States of a small supply for the Weather Bureau work.

Difficulties are still encountered in procuring in the United States a good quality of rubber balloons for atmospheric explorations.

Mention is made at this point of a special form of camera adapted to make a photograph on a single plate of the entire sky from horizon to zenith. This has been developed and tried out by Mr. Fred W. Mueller, with the advice and assistance of Dr. O. L. Fassig, both of Baltimore, Md. The instrument is fully described and illustrated in the Monthly Weather Review.

Since the publication of that paper I am informed by Dr. Fassig that Mr. Mueller has greatly improved the mechanical arrangements of the camera, so that the same results can be obtained in a simpler manner. It is believed the device may have some special use in aeronautics as well as meteorology.

C. F. MARVIN,
Chairman, Subcommittee on the Atmosphere in Relation to Aeronautics.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
Washington, D. C.

REPORT No. 5.

RELATIVE WORTH OF IMPROVEMENTS ON FABRICS.

By THE GOODYEAR TIRE AND RUBBER COMPANY.

REPORT No. 5.

RELATIVE WORTH OF IMPROVEMENTS ON FABRICS.

By The Goodyear Tire and Rubber Co.

If one seeks to determine the qualities which offer the best chance for improvement, without knowing as yet the exact means for effecting such improvement, the procedure is as follows:

Assume that in a theoretically perfect fabric each of the following qualities would be reduced to zero:

Weight (per unit strength).
Diffusion.
Rate of depreciation (dollars per year).
Heating coefficient.
Interest and insurance.
Moisture absorption.

It may be admitted that, in practice, certain of the above qualities can not possibly be reduced below the well-recognized minimum of terrestrial materials, but this minimum is in every case so near zero, compared to the figures for ordinary balloon fabric, that the point is of no practical importance.

Applying the results to a dirigible and taking the items one at a time: If the weight of fabric is reduced to the assumed minimum it will save $\frac{W}{U}$ of the total running expense of the dirigible; where W is the total weight of fabric saved and U is the useful load carried.

If diffusion is entirely eliminated it will save the entire cost of gas (including labor and overhead) except that which escapes through the valves, the interest on the original inflation, and liability to accidental deflation.

If the fabric is made infinitely durable it will save all the depreciation of the gas bag except that due to accidental injury.

If the heating coefficient is reduced to zero it will save the running expense of that part of the control system which serves to correct the effects of heating, plus $\frac{w'}{u}$ of the total running expense of the dirigible; where w' is the weight of apparatus saved.

If cost is entirely eliminated it will save the interest and insurance on the fabric (exclusive of building up).

If the moisture absorption is reduced to zero, it will save the cost of apparatus to correct it, plus $\frac{w''}{u}$ of the total running expense of the dirigible, where w'' is the weight of apparatus saved.

Assume now a modern nonrigid dirigible of 500,000 cubic feet capacity and speed of 40 miles per hour. Other data could be reasonably expected as follows:

W = weight of fabric = 5,000 pounds.
U = average useful load = 6,000 pounds.
10,000 miles per year.
Gross running expense, $100,000 per year.
Gas leakage, 0.5 per cent per day.
Reinflation every three months.
Gas and inflation cost at $0.01 per cubic foot (plus allowance of $10,000 for idle time), $40,000 per year.
Depreciation of gas bag (from weathering and ordinary wear), $20,000 per year.
w' = weight of heat-control apparatus (planes, fuel, and ballast), 1,200 pounds.
Interest and insurance (military) on fabric, $15,000 per year.
w'' = weight of apparatus to counteract moisture absorption (planes and ballast), 500 pounds.

The above data works into the following figures which show the gross expense chargeable to each of the items named:

	Per year.
Weight	$82,000
Diffusion	40,000
Depreciation	20,000
Heating	20,000
Interest and insurance	15,000
Moisture absorbtion	8,000

(These figures are of course largely overlapping and can not be summed up into a total.)

Expressed on a percentage basis for the various qualities sought for, we get roughly the following:

Quality:	Relative importance.
Lightness	44
Gas tightness	22
Durability (dollars per year)	11
Low heating	11
Cheapness	8
Low moisture absorbtion	4
	100

For proportional improvement it will be seen that lightness is by far the most desirable quality, while mere cheapness of fabric is almost the last thing to be sought.

The table also furnishes means of determining whether a proposed change in the design of a fabric is worth while.

In effecting a certain improvement other qualities are generally affected at the same time, sometimes adversely. To determine the degree of net improvement multiply the per cent improvement in each quality by its quality gauge number, and add up the products. If the result is positive a net improvement has been effected proportional to the magnitude of the figure. For instance a 5 per cent saving in weight would he worth while even if accompanied by a 20 per cent increase in cost, other things remaining the same.

It should be carefully noted that this particular scale of improvements is strictly applicable only to a ship of approximately the characteristics above named, and to that only under certain fixed condi-

tions of operation. It is only taken as a rough guide to present day dirigibles in general. Whenever the fabric, the dirigible or its conditions of use are much changed, the fabric improvement scale must be changed accordingly.

It has been argued by some that the economic basis of design can not be applied at all to military work. With this I decidedly do not agree. It is true only to the extent that certain items of cost such as initial investment are often of small, sometimes negligible, importance compared with other items. But if the analysis is complete, it may be put squarely on an economic basis, it being only necessary to estimate the *true* saving for each of the possible improvements above named, *applied to the particular requirements and conditions governing the case in hand.*

It is evident from what has been said that for a dirigible of certain required specifications a definite equation exists connecting all the major qualities of the fabric, from which the fabric may be rigidly designed with respect to maximum ultimate economy.

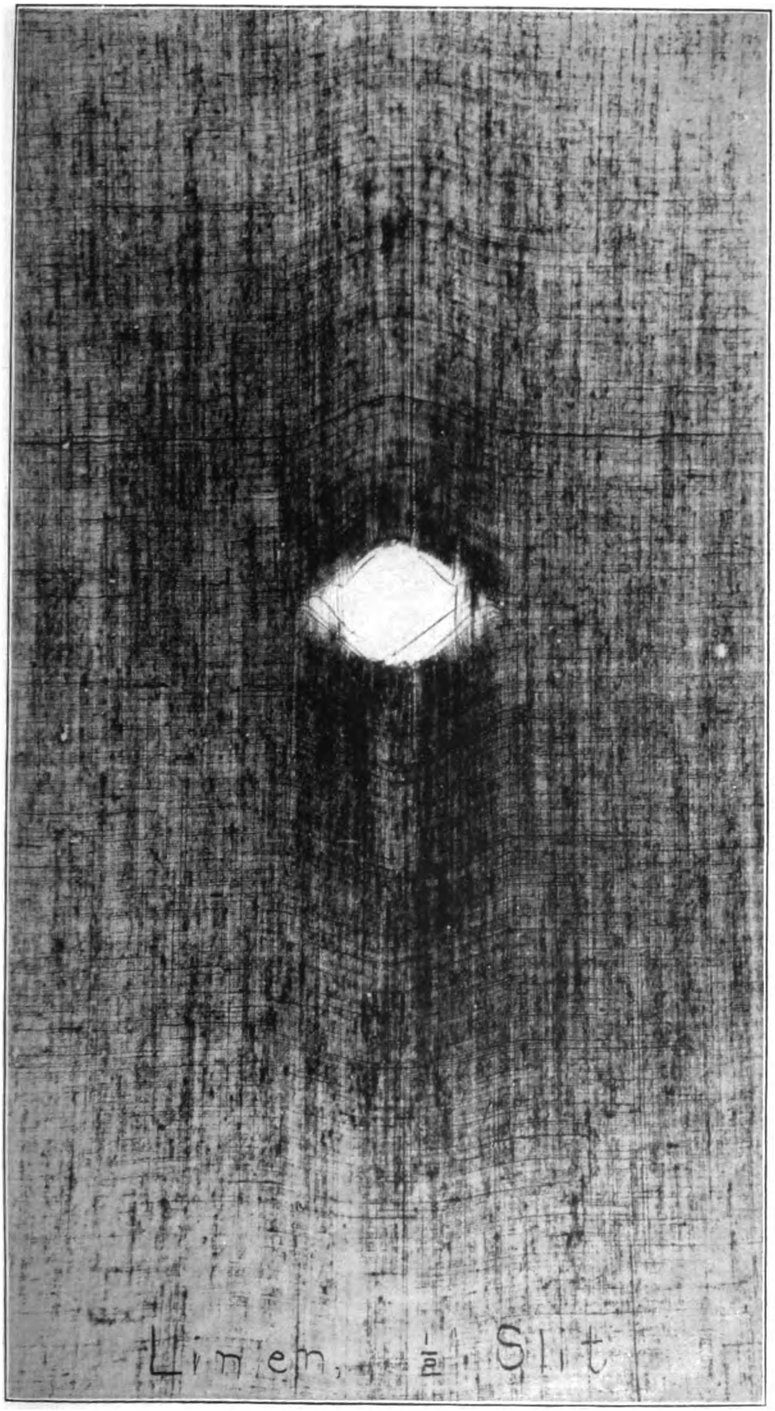
The same principles apply to balloons and aeroplanes. For an 80,000 cubic foot spherical balloon (the *Goodyear*), the following order prevails if used for passenger flights (1 day trips).

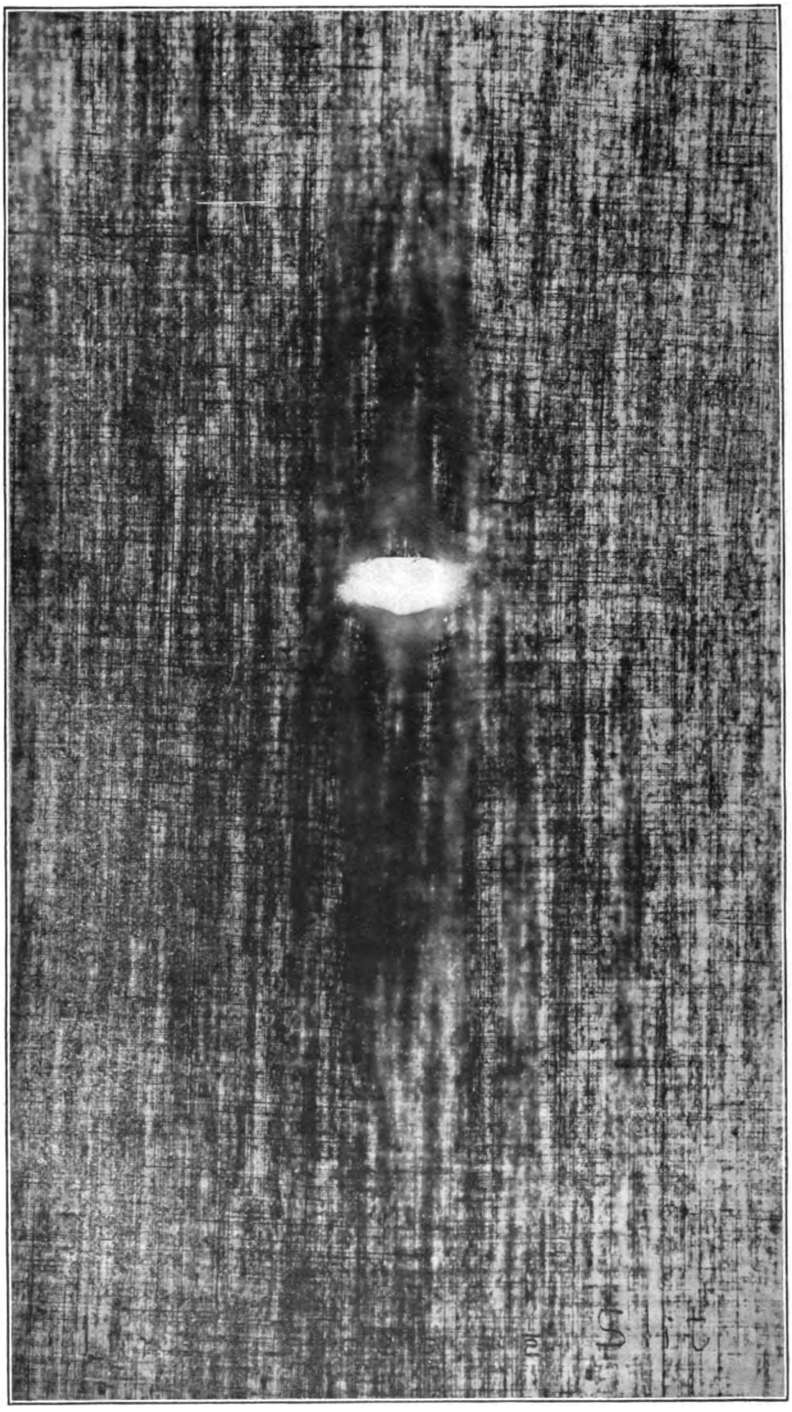
Lightness	32
Durability	22
Low heating	20
Cheapness	16
Low moisture absorbtion	8
Gas tightness	2

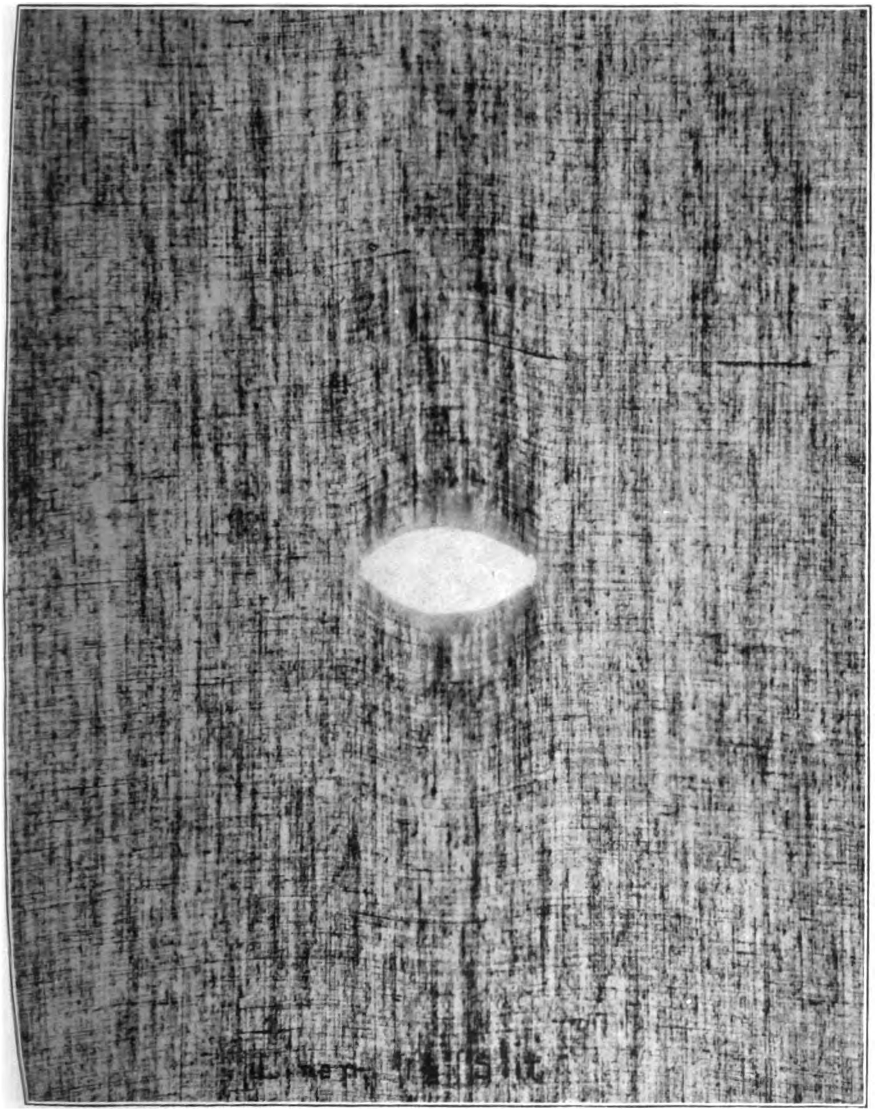
For a 100 horsepower tractor biplane the same six qualities run approximately:

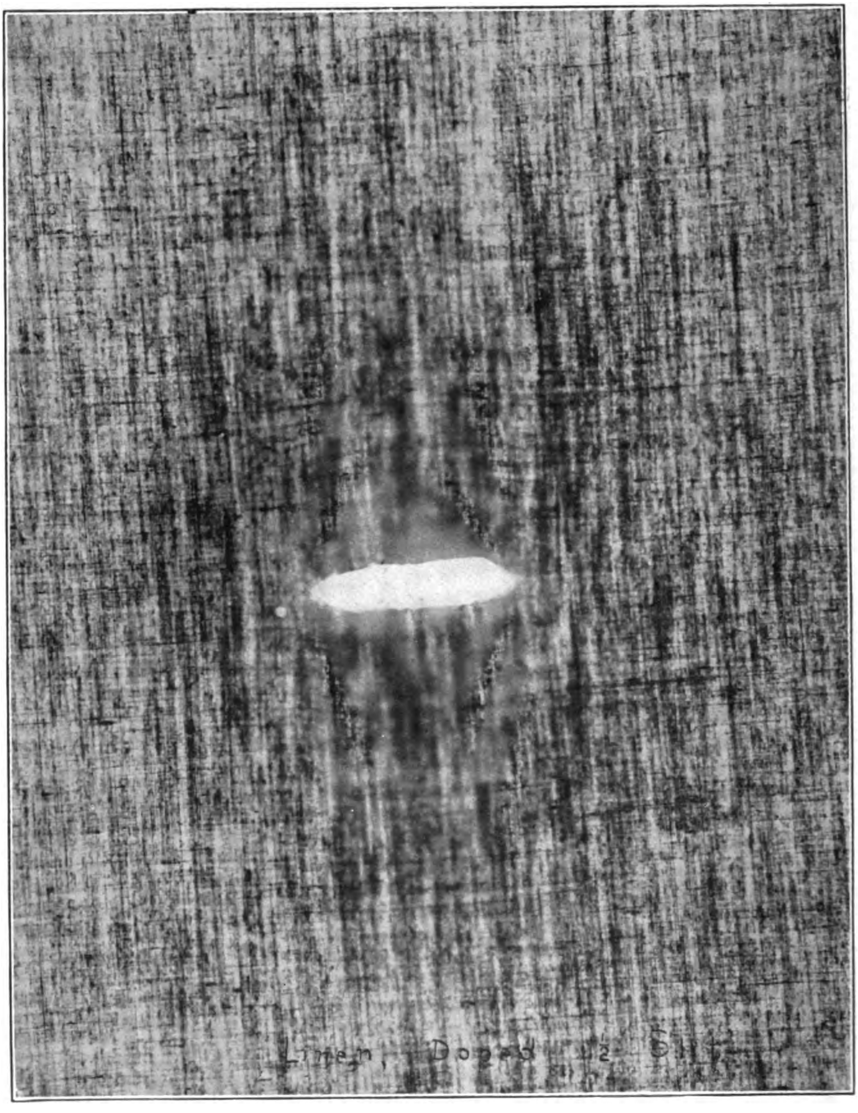
Lightness	60
Durability	20
Cheapness	15
Low moisture absorbtion	5
Air tightness	trifling.
Low heating	0

AUGUST 17, 1915:


Linen, 1/2 Slit







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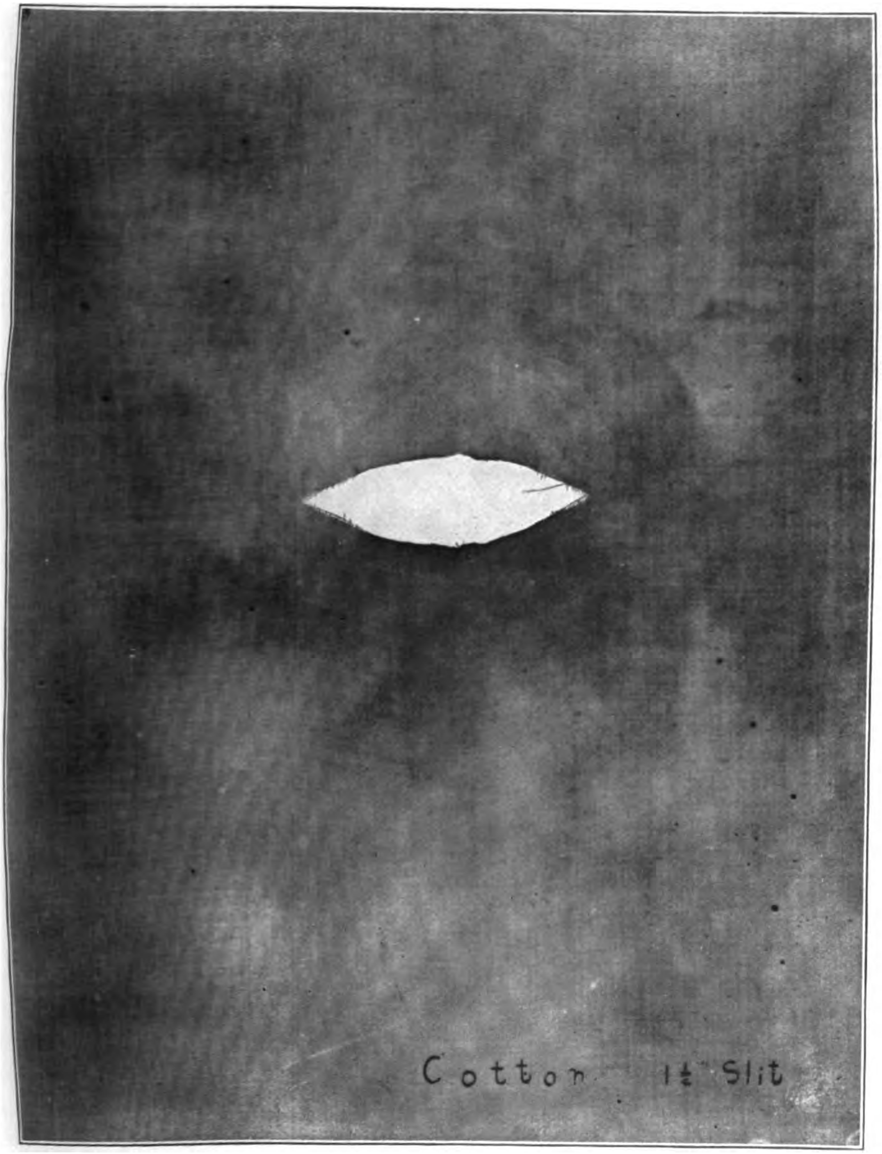
Cotton 1½" Slit

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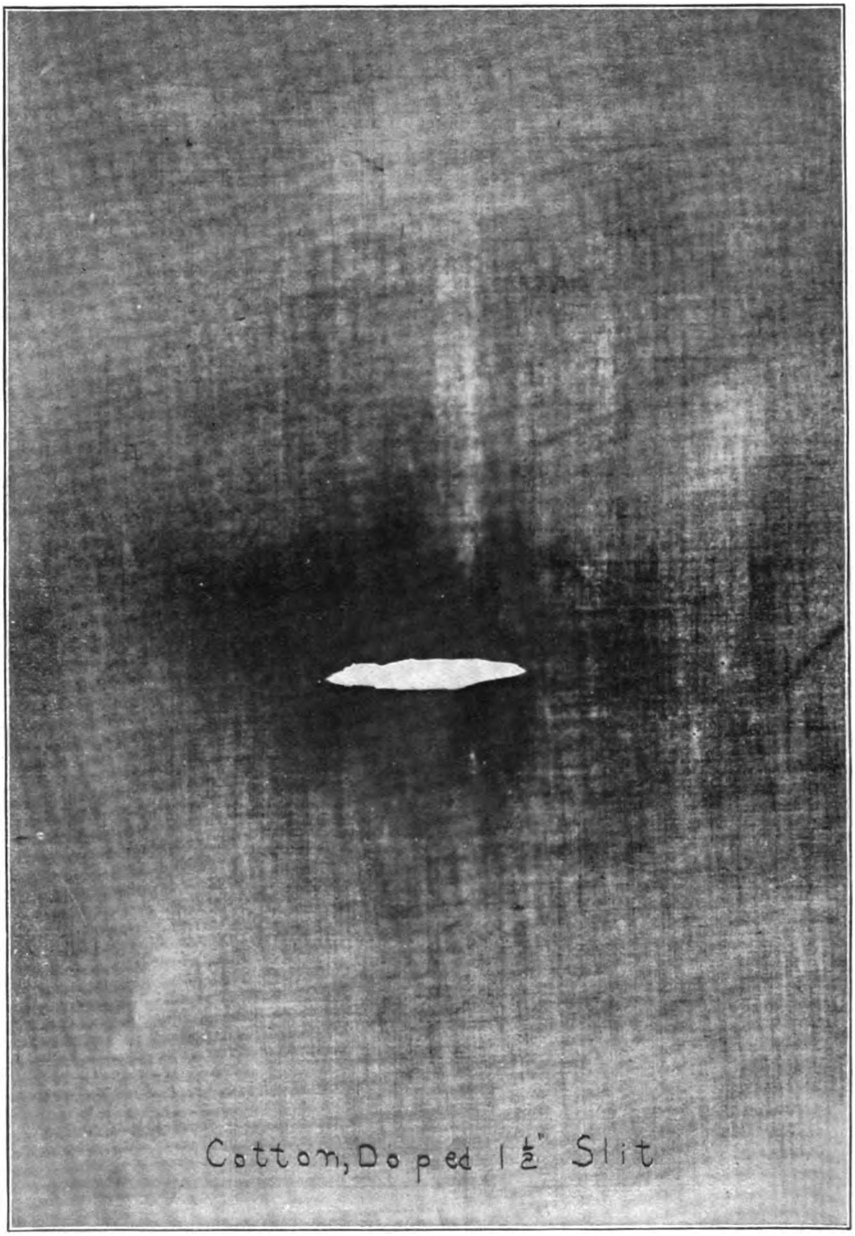
Cotton, Doped 1½" Slit

REPORT No. 6.

IN TWO PARTS.

INVESTIGATIONS OF BALLOON AND AEROPLANE FABRICS.

By THE UNITED STATES RUBBER COMPANY, GENERAL LABORATORIES.

Part I.—BALLOON AND AEROPLANE FABRICS.

By WILLIS A. GIBBONS and OMAR H. SMITH.

Part II.—SKIN FRICTION OF VARIOUS SURFACES IN AIR.

By WILLIS A. GIBBONS.

CONTENTS OF REPORT No. 6.

PART 1.

BALLOON AND AEROPLANE FABRICS.

APPENDIX.

PART 2.

SKIN FRICTION OF VARIOUS SURFACES IN AIR.

REPORT No. 6.

PART 1.

BALLOON AND AEROPLANE FABRICS.

By Willis A. Gibbons and Omar H. Smith.

Note.—Although usually associated, for obvious reasons, balloon and aeroplane fabrics have actually become so dissimilar in many respects, such as materials of construction and requirements for satisfactory results, that for the most part the two will be discussed separately. The tearing and surface friction tests, being common to both, are exceptions to this rule. The plan followed as far as possible in this report has been to give first the results of the various parts of the investigation, with such descriptive matter, data, and plates as are necessary to make the results clear. The data and other details are given in the appendix. For convenience the data is grouped somewhat differently in the appendix, without, it is thought, causing any confusion.

SUMMARY.

The following conclusions are drawn from the results of our tests hereinafter described. It must, however, be remembered that they are based almost entirely on experiment, so care must be used in applying them extensively until they have been tried in actual practice.

COATING MATERIALS.

(1) By proper treatment fabrics can be made noninflammable even though coated with cellulose nitrate varnish followed by spar varnish.

(2) The ordinary cellulose acetate dopes do not make fabric fireproof, although themselves noninflammable. This applies particularly in the case of fabrics doped, then coated with spar varnish.

(3) Fabrics coated on one side with rubber, with the other side doped, would probably give a satisfactory tightening effect and at the same time resist damp weather better.

(4) Maximum efficiency can apparently be best obtained by not stretching the cloth too tightly on the wings before coating.

(5) Stretching and tearing tests give valuable information regarding the suitability of fabrics and should be considered in addition to the tensile strength. The area inclosed by the stretch-load, curve, representing the work done to break the strip, gives an idea as to its resistance to shocks, etc.

BALLOON FABRICS.

(1) Permeability increases greatly with temperature—about 4 per cent per degree C. for samples tested.

(2) Tests made on fabrics with varying weights of rubber indicate that permeability is not directly proportional to the thickness of the layer.

(3) Tearing tests show a great superiority of bias over parallel doubled fabrics.

SURFACE FRICTION TESTS.

(1) For very smooth surfaces the surface friction varies with the 1.8–1.85 power of the velocity; the exponent increases with the roughness, approaching 2 for fabrics with nap on the surface.

(2) Varnished fabrics have nearly as low a resistance as plate glass. The resistance increases greatly as the surface becomes rougher from the presence of loose fibers.

Part I.—AEROPLANE FABRIC.

I. MATERIALS USED.

By far the greater part of the aeroplanes in use to-day have wings made of a textile fabric, usually linen, coated with a more or less waterproof, practically nonelastic varnish. This is ordinarily some form of cellulose acetate, or less frequently cellulose nitrate, with more or less softening material added, and some suitable solvent.

It is ordinarily the practice to apply three or more coats of this varnish, rubbing down with sandpaper after the coating is dry, after which one or two coats of high-grade linseed oil varnish, preferbly a spar varnish, are applied.

1. COATINGS.

The cellulose acetate or nitrate lacquer is chiefly useful because it acts as a sort of waterproof sizing, which shrinks the cloth more or less, and prevents it from changing in tension with the hygroscopic conditions of the atmosphere. The spar varnish protects this layer, which often shows a tendency to peel, and makes the wing more waterproof.

This form of treatment is convenient, and the materials fairly easy to obtain. On the other hand it could hardly be called permanent; the varnish or dope, as it is commonly called, must be applied to the wings of a machine every few weeks, if the machine sees much service.

Another defect noted probably more by the United States military branches than abroad, is that due to deterioration of the underside of the fabric from moisture and bacteria. The dopes owe their shrinking action to the fact that they are colloids, and as such, when applied to the cloth, do not penetrate but remain on one side. As the solvent evaporates, the gel decreases in volume. The most evident decrease is of course in the thickness of the layer, but there is naturally a tendency for the other two dimensions of the layer of drying varnish

to decrease, causing the well known shrinking effect. Other colloids produce the same effect; for example, glue. Another example is the common gummed label, which being unable to shrink, curls up. At Vera Cruz it was found that there was considerable tendency for the uncoated side of the wings to rot, owing to this lack of penetration. On the other hand, those varnishes which penetrate do not produce the shrinking effect.

2. FABRICS.

Of the fabrics linen is the most satisfactory. Ramie and cotton have been used to some extent, but the former is difficult to obtain and the latter does not take the varnish so well as the linen and tears much easier.

Practically all of the linen suited for this purpose comes from abroad, chiefly from Ireland. An investigation of the relative weights and strengths obtainable is, particularly at the present time, rather difficult to make complete. Added to this there is the difficulty of obtaining material of exactly the same grade from time to time. The fabrics in general use weigh 3¾ to 4¾ ounces per square yard, and have a tensile strength, tested at about 65 per cent humidity, of from 60 to 70 pounds per inch for the lighter weight to 100 pounds per inch for the heavier weight.

In the following experiments we have used two grades of linen, No. 1, called high grade, being about the best material immediately obtainable in sufficient quantities for our work, and No. 2, medium grade. The No. 1 weighs 4.6 ounces per square yard and has a tensile strength of about 90–95 pounds per inch warp and 60 pounds filling. The No. 2 medium grade weighs about 3.8 ounces per square yard and has a strength of about 65 pounds warp, 50 pounds filler.

DOPES.

The varnishes or dopes used were three representative products obtained in this country. The cellulose acetate varnishes are probably far from perfect, owing to the difficulty of obtaining a satisfactory product in this country. We understand that the latest European material of this sort is a vast improvement on anything heretofore produced.

The solvents for cellulose acetate commonly used are acetone or tetrachlorethane. The latter is said to be rather dangerous on account of its poisonous properties, and care should be used to allow the vapors, which are heavier than air, to pass through ventilating openings in the floor.

Mention must also be made of a material, the use of which in Europe has been mentioned in news reports. This is a transparent celluloid made of cellulose acetate compounded with a camphor substitute and used in the form of a thin, transparent, noninflammable sheet. These are used for wings instead of cloth, and are said to be very difficult to see at a height of a few thousand feet. Whether this is so or not there is of course this advantage, that the pilot can have a much wider field of view than with ordinary wings.

We were fortunate in obtaining sheets of this material. They are of practically the same strength in both directions.

Thickness.	Weight (ounces per square yard).	Tensile strength (pounds per inch), about—
10/1000	9.33	55
64/1000	59	325

Complete data are given elsewhere.

While the thickest sheets are of course too heavy for wings, they might be used for other purposes as, for example, flooring.

II. STRENGTH, STRETCHING, AND AGING TESTS.

1. STRENGTH.

The samples on which these tests are based were made in two ways: (1) The method used in most cases, except when otherwise specified: The linen was stretched moderately on a frame about 3 by 4 feet, and fastened by tacking. The dopes, etc., were applied to this. (2) The second way (used only in special cases): The linen was doped without first being stretched on a frame.

(1) In general there is a gain in tensile strength due to the dope. No added effect was observed from the varnish.

(2) With a high-grade linen No. 1, the increase in strength amounted to about 10 to 15 per cent. With a medium grade, the increase, particularly in the filler, was much higher, about 40 to 60 per cent.

(3) Tests made on high-grade linen No. 1, coated without being stretched on a frame, showed a much higher tensile increase—in the neighborhood of 40 per cent in some cases. In the first samples, stretched fairly tight before coating, there was evidently not much shrinkage, in the latter samples the cloth shrunk at will, in some cases 3 or 4 per cent. In specifying the increase in strength due to dopes, the method of coating is therefore of importance. The first tests probably approach more nearly the conditions of use on the aeroplane.

(4) Linen coated with rubber, with or without dopes, is stronger than uncoated linen.

(5) Medium-grade linen shows a greater increase in tensile than high-grade linen, in some cases about twice as great an increase being observed.

2. STRETCH.

The stretch at different loads was measured for several different samples and curves plotted. The following points were noted:

(1) The stretch is less up to a certain load with coated fabrics than with the same fabric uncoated.

(2) There is no decided difference between cellulose acetate and cellulose nitrate dopes. The latter is usually supposed to give less shrinking than the acetate. It is possible that this view arises to some extent at least from the fact that fabrics coated with the

nitrate varnish are often more flexible than the others, and therefore appear, on a frame, less taut.

(3) Spar varnish slightly decreases the stretch.

(4) Linen coated with rubber has a greater stretch than the linen without rubber, the latter being, for example, 13 per cent at 96 pounds break, the former 16½ per cent at 100 pounds.

(5) Medium-grade linen, while it acquires a relatively greater strength increase due to coating, has both coated and uncoated a lower ultimate stretch.

	Break.	Stretch.
	Pounds.	*Per cent.*
High-grade linen No. 1	90–95	13½
High-grade linen No. 1 coated with varnish 1877	100	14½
Medium-grade linen No. 2	65	11
Medium-grade linen No. 2 coated with varnish 1877	78	[1] 10.7

[1] By extrapolation.

3. EFFICIENCY.

While it is desirable to have a wing material which will not easily sag, at the same time it is also important to have a fabric yield rather than break under load. A material which has this ability will often by yielding reduce the stress, and so stand usage which would otherwise be disastrous.

A convenient index of this, which for want of a better term we call the efficiency of the fabric, is the work required to break a piece say 1 inch wide and 12 inches long. This is represented by the area included by the stress-stretch curve. We have calculated this value for the various materials examined. The details and data are given elsewhere, but the following points may be mentioned here, observations being based on breaking in the direction of the warp, since the fillers do not show such marked differences.

(1) When the linen is fastened to a frame under fairly strong tension, as would ordinarily be done in covering a wing surface, and then coated, the work required to break a piece of given dimensions is not sensibly greater than that to break the uncoated material, in spite of the fact that the actual tensile strength of the linen seems to be higher after coating. This holds for high and medium grade linens.

(2) Linen coated under no tension required about two and one-half times as much work to break as uncoated linen. The greater stretch and increased tensile strength are both responsible for this.

In view of this the suggestion is made that there is probably some advantage in not using any more tension than is necessary in fastening the fabric to the frames before coating. The dopes have considerable shrinking power, measured linearly, and by allowing the cloth to shrink a certain amount the slack will be taken up and at the same time a greater efficiency obtained. A stress from collision, etc., will then have a chance to exhaust itself without breaking the

cloth, since the cloth can "give" and thus adjust itself to decrease the amount of the stress.

We understand that one manufacturer of the varnish at least recommends this. We have also been told that in some cases, as when a wing collides with an obstruction in landing, a dent may be formed in the fabric without breaking, this dent later disappearing. Since the varnish coating is noncrystalline, and can really be considered in a sense a supercooled liquid, it seems quite likely that there may be some flowing action permitting a slow readjustment of this sort.

(3) The use of spar varnish seems to have no decided effect on the efficiency.

(4) Rubber on one side of the linen with various coatings showed an efficiency about 75 per cent higher than that of linen without rubber, coated on frames. This is of course partly due to the greater stretch of such a fabric, as already noted. It would be interesting to find by practical experiment whether a fabric with rubber on one side can be made to shrink sufficiently for use on a wing. From our small experiments it seems likely that it would be satisfactory. If so, it would have the advantage of being protected on the under side, a matter of consequence in certain localities, as already shown.

4. AGEING.

Samples subjected to continuous exposure for three weeks in a location such that the material felt the full effect of sun and weather throughout the day gave the following results on tests:

(1) The tensile strength was 66 to 75 per cent of the original.

(2) In all cases samples had been greatly affected by the weather, in appearance and feeling. Spar varnish coatings cracked and pealed; samples doped but not coated with spar were more or less scrubbed off by the weather and had evidently deteriorated.

(3) In several cases samples doped and varnished with spar varnish showed a smaller decrease in tensile than those unvarnished, but the effect was not so pronounced as would be expected.

(4) Cellulose acetate coatings seemed more affected by the ageing than cellulose nitrate. This is probably due to the hygroscopic character of the former material, and to the ease with which oils are blended with the latter, making it more waterproof.

III. ABSORPTION OF WATER.

Samples were first weighed, then dried at 95–100° C., and reweighed, after which they were tested. One piece of each was soaked in water at an average temperature of 25° C., another was hung in a saturated atmosphere at the same temperature—for two weeks in both cases. The samples were removed, surface water wiped off the ones that had soaked, after which they were weighed in a weighing bottle. They were then dried at 95–100° C., and reweighed. These data gave the amount of moisture normally present, the amount of water taken both by soaking, and by standing in moist air, and the amount of material washed out by soaking in water. The following results were obtained:

(1) Loss from soaking amounts to 3 to 7½ ounces of the weight of the sample.

(2) Compared with dried samples, fabrics exposed to saturated atmosphere showed 6 to 13 per cent moisture.

(3) Soaking caused the samples to take up 30 to 60 per cent of water.

(4) Cellulose acetate coatings suffer more from soaking than cellulose nitrate.

(5) Fabrics coated with rubber on one side, and doped on the other side, show a smaller absorption of water on soaking, and a smaller increase in weigh due to moisture taken up on standing in a saturated atmosphere than unrubberized fabrics. The effect of spar varnish, in preventing the absorption of water was here very apparent.

IV. FIREPROOFING.

Tests on fire resisting properties of various fabrics were made, to find the effect of the different coatings, and to investigate the possibility of impregnation of fabric with fireproofing materials.

Method of test.—A strip of the fabric ¾ inch wide, was held horizontally, coated side up, and the end touched to a Bunsen flame for a distance just sufficient to ignite. The time required to burn back for a distance of 3½ inches was observed; in cases where the flame was extinguished before this point was reached, the actual distance was noted. Care was taken to avoid drafts.

(1) All coated fabrics not otherwise treated were inflammable; that is, the piece continued to burn after the source of heat was removed.

(2) Spar varnish seemed to retard the burning of fabric coated with cellulose nitrate, and to accelerate it in the case of fabric coated with cellulose acetate.

(4) Fabrics impregnated with ammonium chloride and ammonium phosphate were more fireproof than those impregnated with boric acid. In every case the first two prevented the flame from being self-propagating even when the fabric was doped with cellulose nitrate.

(5) It is interesting to note (see appendix) that fabric impregnated with ammonium chloride has an increased initial tensile strength, but deteriorates more rapidly on exposure. This is probably on account of hydrolysis of the cellulose (fabric). These experiments lead one to believe that by further investigation a thoroughly statisfactory material may be found, which will make fabric fireproof and at the same time not injure it.

Part II.—BALLOON FABRIC.

I. MATERIALS.

Cotton is the most widely used fabric for balloons, in spite of the fact that it is one of the weakest textile fabrics. Silk, the strongest textile fabric, is used to some extent in France and Italy, when lightness is the most important feature. In Germany, it is usually considered dangerous, owing to its electrostatic properties. Its

high cost is another objection, when large amounts are needed, as in a Zeppelin type dirigible.

Ramie has been used, but is reported to be unsatisfactory, owing to the difficulty in rubberizing.

Linen has been used, with success, and on account of its greater strength possesses considerable advantage over cotton. The greater tearing resistance of this material as compared with cotton is particularly important. On the other hand, as already stated, it is more difficult to obtain, made according to specifications, than cotton.

In large balloons, rubber is used almost without exception. Other materials are less permeable to hydrogen, but none possess the same properties of adhesion, ease of working, and flexibility. Several layers of fabric can be used, thus increasing the strength and gas-tight properties of the material, whereas oiled fabrics are ordinarily used in a single layer, and to keep this tight a thin closely woven fabric must be used. Furthermore, oiled fabrics are subject to change from heat and cold and must be handled with care. They are, however, cheaper than rubberized fabrics.

We have obtained various cotton fabrics suitable for use in balloon cloth, and from the tests on these, and also from published data of tests made in Europe, have endeavored to establish some relation between the weight and maximum strength obtainable at that weight. Differences in testing conditions, such as humidity and method of testing, not usually specified, cause a certain variation, so the probable limits of strength of each weight are given.

Until recently it was very difficult to obtain a satisfactory fabric made in this country. Labor and other conditions in Europe have permitted a greater concentration upon the spinning and weaving of such fabrics. The results have been that until recently no cotton fabrics comparable to those made in Europe could be obtained.

Recently there have been produced in this country fabrics which from the standpoint of weight and strength are probably as good as those made in Europe. It is to be hoped that the same perfection in spinning and weaving may also be obtained.

In the former operation cotton manufacturers usually admit the superiority of European material, but probably in time this can be met. This point is important, in order to get a fabric as free from flaws as possible.

The mean results of our tests and those from abroad would indicate the following:

Weight of fabric.	Strength warp and filler.
Ounces per square yard.	*Pounds per inch.*
2	30
2½	42
3	53
3½	65
3¾	74

II. STRENGTH AND AGEING TESTS.

(1) *Effect of structure.*—Ordinarily balloon fabrics are made of two or more cloth layers, one of these usually on the bias. A layer of rubber is between each ply of fabric and a layer on the face of the fabric which comes in contact with the gas. The outside surface may or may not be coated with rubber and is sometimes treated after the balloon is made with cellulose acetate varnish. Parallel fabrics—that is, two or more layers of fabric with the warp threads all running in the same direction—have been used to some extent in France. They are supposed to be stronger, but tear more easily. Since cotton tears quite easily under ordinary conditions, it seems highly desirable to adopt some such method as biasing to prevent tearing. While the biased fabric does not show so high a tensile strength test, it must be remembered that the stresses on a dirigible balloon which cause trouble are not the simple ones due to internal pressure, weight of load, etc., but those localized in one area due to sudden pulls on ropes, etc. It is important to have a fabric that will not continue to tear after a tear is once started.

Tensile strength tests made on 1-inch strips showed that the strength of a 2-ply parallel fabric was not necessarily twice that of the single ply of uncoated fabric. On the other hand, double bias fabrics show a greater strength than that of the single ply of fabric when the stress is parallel, for example, to the warp of the unbiased piece.

	Balloon cloth made from—	
	Fabric No. 1.	Fabric No. 2.
Strength of fabric, uncoated warp	70	50
Strength of 2-ply parallel fabric warp	125.5	92.6
Strength of fabric 2-ply bias warp of unbiased ply	85	66
Tensile strength by bursting test, 2-ply bias	100	85

Ageing for 13 weeks, the samples being continuously exposed to the weather, caused a decrease in tensile strength of about 5 per cent. The samples were exposed during the winter months, from January 1 to about April 1.

Other samples exposed for one month, from August 20 to September 20, showed a decrease of about 8 to 10 per cent in tensile strength in the warp and from 0 to 6 per cent in the filling. The rubber was apparently unaffected.

III. PERMEABILITY OF BALLOON FABRICS.

The permeability was measured by the chemical method similar to that used at the National Physical Laboratory of Great Britain. In this method the fabric is held in a cell, which is divided by the fabric into two compartments. Dry purified hydrogen at a pressure of 70 millimeters of water is passed through one side, while air is drawn through the other, dried and passed through an electric furnace, which burns the hydrogen present in the air from diffusion to water,

which is absorbed and weighed. The cell is kept at constant temperature by immersion in a thermostatic bath. The permeability is expressed in liters of hydrogen, measured at 0° C., 760 millimeters per square meter of fabric per 24 hours.

In France the Renard-Sourcouf balance is ordinarily used. This measures the net volume of gas lost by diffusion through the fabric. It does not in reality measure the loss of hydrogen, since air passes in while hydrogen passes out. According to T. Graham,[1] the relative rates of diffusion of nitrogen, air, and hydrogen are as follows:

Diffusion through rubber.

Nitrogen	1
Air	1.149
Hydrogen	5.5

With the Renard balance, while 5.5 volumes of hydrogen pass out, according to the above figures, 1.149 volumes of air pass in, giving a net change of 4.351 volumes. In other words, for an apparent loss of 10 liters per 24 hours per square meter, we should have an actual loss of 12.6 liters, as measured by the chemical method. (We have not had an opportunity to test fabrics measured by the gas balance method.) The volume loss is of course important, and if on further investigation it is found that there is much variation in the ratios given by the Graham experiments for different kinds of rubber it would be well to make both tests standard. In fact, the introduction of auxiliary coatings of cellulose esters, etc., makes this of immediate interest.

(1) EFFECT OF VARYING AMOUNTS OF RUBBER.

The permeability decreases with increasing weight of rubber as a general rule, but does not seem to be proportional to it.

Weight of rubber between plies (ounces per square yard).	Permeability at 15° (by extrapolation).
1.65	50
3.11	9
5.11	9

This is in accord with the observation of Austerweil,[2] who found that the permeability of two rubber membranes, 918 and 1,675 grams per square meter respectively, was practically the same for the first 100 hours. The rates diverged up to 400 hours, after which they were again constant. This, according to Austerweil, marked the point when both membranes were saturated. Between 100 and 400 hours the thinner membrane became saturated more rapidly than the other, and so showed a greater rate of diffusion.

[1] Phil. Trans., 1866, p. 399. [2] Die Angewandte Chemie in der Luftfahrt, p. 67.

(2) EFFECT OF TEMPERATURE.

Experiments conducted in England at the National Physical Laboratory[1] show that the permeability rises rapidly with the temperature. For two samples they found the following results:

Diagonally doubled, 3 layers rubber	15.5° C.— 6.71 1 22.1° C.—10.84 1
Parallel doubled, 2 layers rubber	15.5° C.—12.3 1 22.1° C.—21.5 1

These figures show more than 9 per cent increase in permeability per degree.

We have made tests at approximately 20, 30, and 40° C., and found in every case a marked temperature coefficient. If the values of permeability and temperature are plotted, it will be noted (fig. 9, appendix) that the curve rises more rapidly with increasing temperature. Our results show a temperature coefficient about one-half that given in the data just cited. It may be that the nature of the rubber compound has considerable bearing.

This high temperature coefficient is of peculiar importance in this country, where the aeronautic activities of both Army and Navy are centered in the South. It seems advisable that this be considered in specifying the minimum gas leakage allowable when contracting for dirigible balloons, and that some temperature be stated, since a balloon tested at Pensacola would, without extra precautions, show a higher loss than one in the vicinity of New York. A correction to a standard temperature could probably be made.

This also shows the advisability of providing adequate arrangements to prevent too high a temperature in hangars. I understand that in Europe double roofs, with fans and other suitable cooling devices are used.

(3) EFFECT OF COATING CLOTH WITH CELLULOSE ESTER LACQUERS.

It has been the practice in Europe for some time, apparently, to coat the outside of balloons with some sort of varnish. These are sold under various names, but in general are cellulose acetate lacquers. They are used to cut down wind resistance, to protect the fabric, and to render it gas tight in cases where the rubber has deteriorated.

Samples were given four coats of cellulose nitrate and cellulose acetate lacquers 1876 and 1877, respectively, the lacquer being applied to the cloth. In both cases the improvement in permeability was definite, though small, amounting to from 1 to 1½ liters per square meter per 24 hours.

(4) EFFECT OF COATING RUBBER WITH CELLULOSE ESTER LACQUERS.

It seemed likely that the small improvement noted above was due to the fact that cloth offers a poor surface for obtaining a tight coat, at least for a thin film. To verify this tests were made with the same

[1] Tech. Report Adv. Committee for Aeronautics, 1910-11, p. 60.

materials in the same amounts on the rubber side. The improvement was very marked here, amounting to 50 per cent or more of the value found for the same fabric uncoated. In one case there was a reduction from 11 liters at 20° C. to 4 liters at the same temperature. Unfortunately these lacquers are not suited for use on rubber surfaces since they peel off. It is to be hoped that a marked improvement may be made in them, since their use for this purpose seems very promising. The inflammability of cellulose nitrate is of course a drawback, but obviously a balloon filled with hydrogen must be carefully protected from fire, however noninflammable the material used in its construction. It is, moreover, a simple matter to obtain cellulose nitrate blended with oil to give a flexible coating.

(5) EFFECT OF COATING RUBBER WITH GELATIN COMPOUNDS.

A flexible gelatin compound on the rubber surface in about the same amounts as the coatings used in (4) and (5) was tested and found to give a very low permeability:

Original permeability at 20° C., 11 liters per square meter per 24 hours.
Permeability after coating with gelatin compound at 20° C., .8 liter approximately per square meter per 24 hours.

Part III.—TESTS ON BALLOON AND AEROPLANE FABRICS.

I. TEARING TESTS.

To obtain some knowledge of the behavior of aeronautic fabrics under stresses somewhat similar to those existing in aeroplanes and balloons, the test used by the National Physical Laboratory [1] was employed.

Method.—A piece of fabric is clamped in the jaws, and in the center of this a slit of definite length is cut perpendicular to the line of pull. When stress is applied, the cut opens, and if the load is increased the tear widens in a direction perpendicular to the stress and the sample finally breaks. The threads parallel to the line of stress bend inward on either side of the slit; those perpendicular to the strain bend away from the cut. The localization of strain on the thread at the ends of the slit is evidently caused by the pull being transmitted from the longitudinal threads to the transverse threads, due to the take-up in weaving. The general effect of stretching coated and uncoated fabrics is shown in the photographs taken of tests. (Appendix, Plates I–VI.) The wrinkling of the coated fabric around the cut, producing a poor impression, is particularly of interest, showing how the disturbance is more localized than in the case of uncoated fabric.

A fair index of the ability of fabrics to resist tearing may be obtained by plotting the results for the point at which the tear starts to widen and where rupture occurs against the size of cut. The factor found by dividing the breaking load by the width of slit gives a means of comparison which seems to have some value. (See appendix for data and curves.)

(1) The load to break falls off more rapidly with increasing size of slit in the case of a doped fabric than with an undoped fabric.

(2) Cotton is much inferior to linen.

[1] Tech. Report of Adv. Com. for Aeronautics, 1910–11, p. 72.

(3) Parallel double balloon fabric tears more easily than bias doubled fabric, particularly for small cuts. Furthermore, a parallel fabric tears evenly in a straight line, while in the case of the bias a general rending of one layer occurs, while the other is distorted rather than torn. It can be readily seen that the effect of tearing on the parallel fabric in a balloon would be much more disastrous.

II. SURFACE FRICTION TESTS.

Tests on the resistance of various fabrics were made in the wind tunnel at the Washington Navy Yard.

The method used was to suspend vertically a glass plate about 34 inches wide and 9 feet long so that its long edge is in the direction of the air flow. The following edge of the plate is connected with the balance, allowing the horizontal moment about one knife edge to be measured.

Corrections were found and used for the wires suspending the plate. The ends of the plate fitted into slots in struts of stream line form. The wind passing the slot into which the leading edge fitted caused a diminution in pressure, giving the effect of a thrust on the plate against the wind. The wind caused a compression in the slot in which the following edge fitted, likewise giving the effect of a thrust against the wind. The amount of pressure developed in each slot was observed with a hook gauge manometer, and from this and the area of the edges could be calculated the correction to be added for each speed.

The resistance of the plate glass was taken as standard and found at 30, 40, 50, 60, and 70 miles per hour. Various samples of fabric were then attached, covering both sides of the glass completely in each case, and the resistance measured at different speeds.

Complete data will be found elsewhere, but the following general points may be mentioned here. Taking, for example, the resistance of plate glass as 1, at 70 miles per hour, we have the following comparative resistances at this velocity:

Experiment No.	*At 70 miles per hour.*	
1	Plate glass	1.000
5	Linen No. 1 (high grade)	1.362
2	Linen No. 1 (high grade), 1 coat varnish No. 1876	1.162
3	Linen No. 1 (high grade), 3 coats varnish No. 1876	1.108
4	Linen No. 1 (high grade), 3 coats varnish No. 1876, 1 coat spar varnish	1.061
6	Linen No. 1 (high grade), 3 coats varnish No. 1877	1.085
7	Linen No. 1 (high grade), 3 coats varnish No. 1877, 1 coat spar varnish	1.061
8	Linen No. 1 (high grade), 3 coats varnish No. 1877, 2 coats spar varnish	1.078
9	Balloon fabric No. 3, cloth outside, double parallel	1.965
10	Balloon fabric No. 3, cloth outside, double parallel, freshly singed	1.654
11	Balloon fabric No. 3, cloth outside, double parallel, singed and coated once, No. 1876	1.345
12	Balloon fabric No. 3, cloth outside, double parallel, singed and coated three times, No. 1876	1.107
13	Balloon fabric No. 3, cloth outside, double bias	1.902
14	Balloon fabric No. 3, cloth outside, double bias, freshly singed	1.762
15	Balloon fabric No. 6, cloth outside (specially woven fabric), double bias	1.528
16	Balloon fabric No. 6, cloth outside (specially woven fabric), double bias, freshly singed	1.372
21	Aeroplane fabric, rubberized, No. 23	1.079
22	Aeroplane fabric, aluminum coated, No. 24	1.101

I. From these figures it will be seen that we may roughly divide surfaces into groups as to wind resistance.

(1) Those which are what might be called continuous; in this case the resistance probably increases simply as the surfaces deviate from a true plane due to lumps and other unevennesses. Plate glass, doped, varnished, and rubberized fabrics come in this class. The resistance does not exceed 1.20, glass being 1.

(2) Those which have a discontinuous surface, i. e., such as would be presented by a perfectly smooth woven material, as a wire gauze; linen and singed cotton approach this. Here the resistance is between 1.35 and 1.7.

(3) Those which have a discontinuous surface to which is added other roughnesses, such as arise from nap. Unsigned cotton is in this class, and the resistance is 1.5 or more.

II. It is interesting to note the great improvement produced on balloon fabric by the use of one or more coats of some sort of varnish.

III. The *difference* in resistance between an uncoated fabric of class (3) and plate glass is very appreciable at high speeds, being about 0.013 pound per square foot at 70 miles per hour. This would mean a total head resistance in a large machine of about 18 pounds, or a decrease in lifting power of 150–180 pounds. However, as can be seen from the list, it is fairly simple to cut down the resistance until it approximates that of glass.

APPENDIX

TO

REPORT No. 6, PART 1.

[Containing details, data, and plates.]

LINEN FABRICS.

Linen is the most widely used material for aeroplane wings, on account of its great strength and toughness. The grades now on the market have weights and strengths as shown:

	Weight (ounces per square yard).	Strength.	
		Warp.	Filler.
I	3.67	65.0	54.4
II	3.78	69.5	49.2
III	3.87	80.7	79.0
IV	4.04	86.9	74.0
V	4.09	90.2	82.7
VI	4.48	82.9	100.1
VII	4.60	95.0	60.0
VIII	4.86	90.4	102.5

In Great Britain there has recently been adopted the method of testing the sample wet, after soaking some time. This is to avoid error due to humidity changes. While this method may seem somewhat arbitrary, it is convenient and nearer the conditions of use than a test on absolutely dry material. They figure that this test corresponds to what could be expected at a theoretical humidity of 111 per cent.

Tests on transparent cellulose acetate sheets.

No.	(1) Thickness.	(2) Weight (ounces per square yard).	(3) Tensile strength (pounds per inch).		(4) Maximum difference in tests (in per cent of average value).	
1	10/1000	9.33	55.3	57	10.8	10.5
2	16/1000	15.49	106.3	85.8	14.1	8.1
3	24/1000	22.96	127.1	130	30.6	25.2
4	32/1000	30.35	178.6	187.7	21.2	2.6
5	64/1000	59.02	326	345.8	10.7	.8

Tests made on Riehle machine, 1-inch strips, 1-inch jaw, 3 inches between jaws; speed, 18 inches per minute.

The strength was measured both ways on each sheet, since it was thought that the material might show a grain, such as often occurs in materials in sheet form which have been made by a calendering process. Except in the case of No. 2, there is no perceptible difference in strength. The material runs fairly uniform in strength except for the one sheet No. 3. Column 4 shows the difference between the highest and lowest tests, compared to the average.

The material is quite flexible, in thin sheets, and can be bent double several times in one place without cracking. On the other hand, it tears very easily when once cut. It is noninflammable.

STRETCHING TESTS.

Figures 1–4 show the relation between load and per cent stretch. The numerical values for the tests are given on page 155 and need little comment.

The tests were made on a Riehle fabric-testing machine, and measurements were made on an initial distance of 20 inches, so the results are probably quite accurate. The jaws moved apart at a rate of 6 inches per minute.

It is interesting to note that the rate of stretch is usually low in doped fabrics up to 10 to 20 pounds load, after which it rises more rapidly. On the other hand, the uncoated fabrics tend to be just the opposite of this—that is, there is a considerable stretch at first under light load, up to say 20 pounds, then the "slack" having been removed from the fibers, the stretch is much slower. It will be noticed that this holds true even for samples when the total stretch of the coated fabric greatly exceeds that of the uncoated, as in figure 2, Curves VIII, IX, X, XI, when the fabric was not stretched on a frame without coating. The stretch of the coated fabric only becomes equal to that of the uncoated at loads of 12 to 20 pounds.

The application of this seems to lie in the fact that ordinarily even at high speeds the loading due to wind pressure is very light. According to Austerweil [1] even at highest speeds the load would not amount to more than 145.5 kilograms per meter, or about 8 pounds per inch. Ordinarily it would be much less. It would seem therefore that from the standpoint of keeping the fabric taut against stretching just as good results could be obtained by putting it on loosely enough to allow shrinkage, and get the benefit of increased tensile strength and efficiency shown by the fabrics in Curves VIII–X, inclusive.

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[1] Die Angewandte Chemie in der Luftfahrt, 179.

Stretch of aeroplane fabric.

Fabric.	Curve.	Stretch under load of (pounds per inch)— 10	20	30	40	50	60	70	80	90	100	110	Efficiency—in (1-inch by 12-inch strip) foot-pounds.
Linen No. 1:													
Untreated warp	I	3.65	7.10	8.30	9.35	10.10	10.65	11.15	11.55	12.05	(96) 12.35	....	8.67
Untreated filler	I	1.62	2.37	2.90	3.37	3.75	4.16	......	......	......	......	....	....
Varnish 1875—													
W	II	1.25	3.75	6.66	9.25	10.58	11.83	12.92	13.75	14.75	......	....	7.77
F	II	.80	1.68	1.86	2.12	2.66	3.19	3.73	4.36	......	......	....	....
Varnish 1876—													
W	III	1.17	3.58	7.50	9.92	11.50	12.58	13.50	14.12	14.50	15.00	....	9.62
F	III	.75	1.58	2.58	3.42	4.11	4.42	5.25	5.62	6.00	......	....	....
Varnish 1877—													
W	IV	1.75	4.7	7.42	9.35	11.25	12.00	12.83	13.33	14.12	14.50	14.75	10.98
F	IV	.75	1.75	3.00	3.50	4.00	4.75	5.25	6.00	(86) 6.75	......	....	....
Varnish 1875 and Spar—													
W	V	1.17	3.42	5.92	8.00	9.33	10.62	11.50	12.08	13.00	(95) 14.00	....	7.54
F	V	1.00	1.75	2.75	3.33	4.25	4.62	5.33	6.00	(86) 6.50	......	....	....
Varnish 1876 and Spar—													
W	VI	1.10	3.5	6.42	8.80	10.80	11.25	12.16	13.00	13.53	14.00	....	8.75
F	VI	.83	1.75	2.75	3.75	4.33	4.92	5.33	5.92	6.37	(96) 7.00	....	....
Varnish 1877 and Spar—													
W	VII	1.75	4.00	6.50	8.75	10.50	11.75	12.12	12.80	13.00	(96) 14.2	....	7.32
F	VII	1.04	1.99	2.85	3.55	3.81	4.08	4.60	4.86	......	......	....	....
Linen No. 1, coated, without prestretching, coated with—													
Varnish 1875—													
W	VIII	5.00	6.89	11.44	15.33	17.55	18.89	20.00	21.17	21.75	22.67	120-23.67 23.33	19.41
F	VIII	2.20	3.33	4.33	5.07	5.76	6.33	7.00	7.37	(88) 8.13	......	....	....
Varnish 1876—													
W	IX	3.16	7.83	12.00	15.08	17.08	18.08	19.66	20.42	21.17	22.00	120-23.83 22.50	19.11
F	IX	2.00	3.80	4.77	5.25	6.00	6.37	6.50	7.00	......	......	....	....
Varnish 1877—													
W	......	2.81	10.43	15.00	17.50	18.75	19.75	20.43	21.06	21.56	22.12	22.83	18.19
F	......	1.63	3.08	4.16	4.58	5.16	5.66	6.16	6.37	......	......	....	....
Linen No. 1:													
Rubberized—													
W	IR	7.42	11.25	12.44	13.44	14.06	14.56	15.06	15.56	15.92	16.50	....	12.80
F	IR	2.25	3.50	4.00	5.25	5.8	6.25	......	......	......	......	....	....
Rubberized—													
Varnish 1875—													
W	......	1.92	5.58	8.58	10.92	11.66	13.08	13.92	14.42	14.92	15.33	16.25	11.77
F	......	1.92	2.81	4.00	5.12	5.62	6.37	6.50	7.00	......	......	....	....
Varnish 1876—													
W	......	2.56	7.25	10.37	12.12	13.19	14.00	14.6	15.19	15.6	16.19	120-17.25 16.75	15.16
F	......	1.37	3.00	4.00	5.12	5.5	6.00	6.57	6.81	......	......	....	....
Varnish 1877—													
W	......	2.75	7.08	10.5	12.25	13.33	14.17	14.92	15.5	15.92	16.37	16.70	13.46
F	......	1.62	3.19	4.19	5.08	5.66	6.17	6.50	6.92	7.25	......	....	....
Varnish 1875—													
Spar—													
W	......	1.75	6.75	9.25	11.50	12.68	13.31	14.06	14.69	15.44	15.5	....	12.25
F	......	1.33	2.42	3.50	4.50	5.16	5.58	6.00	6.16	......	......	....	....
Varnish 1876—													
Spar—													
W	......	2.50	7.94	11.06	12.81	13.77	14.69	15.37	16.00	16.37	16.62	17.00	13.64
F	......	1.37	3.06	4.44	4.62	5.19	5.56	6.19	6.31	......	......	....	....
Varnish 1877—													
Spar—													
W	......	2.66	6.66	9.83	11.5	12.92	13.83	14.58	15.08	15.58	16.08	16.5	12.66
F	......	1.33	2.42	3.58	4.42	4.92	5.33	5.50	5.87	......	......	....	....

Stretch of aeroplane fabric—Continued.

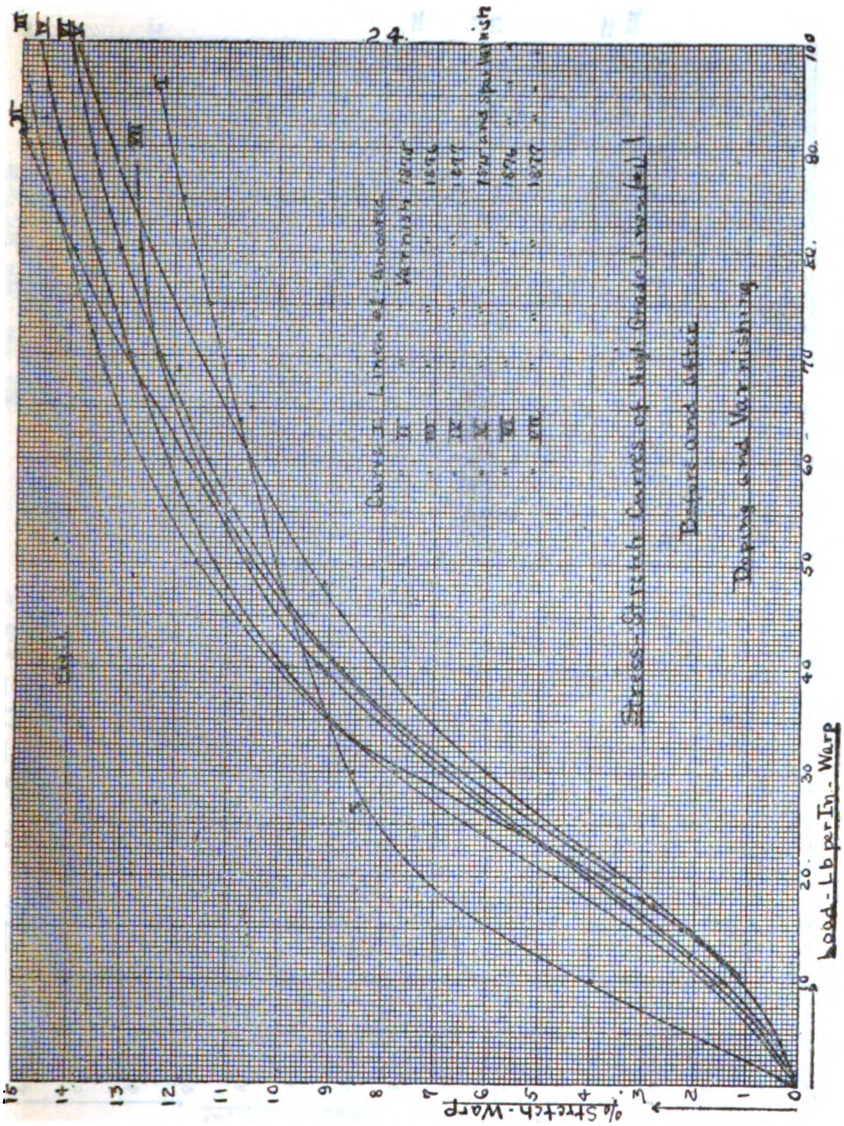
Fabric.	Curve.	Stretch under load (pounds per inch).										Efficiency in (piece 1 by 12 inches) foot-pounds.
		10	20	30	40	50	60	70	80	90	100	
Medium-grade linen No. 2:												
W	IM	5.08	7.42	8.42	9.16	9.50	10.12	......	......	......	......	4.51
F	IM	3.75	5.00	5.75	6.12	......	......	......	......	......	......	....
Linen No. 2:												
Varnish 1875—												
W	IIM	1.58	4.16	6.42	8.67	9.92	10.62	11.50	......	......	......	4.77
F	IIM	.67	1.42	2.33	3.16	3.83	4.42	5.00	5.12	5.50	......	....
Varnish 1876—												
W	IIIM	1.33	3.08	5.08	6.58	7.50	8.33	8.75	9.50	......	......	4.56
F	IIIM	1.17	2.50	3.33	4.92	5.83	6.50	7.12	......	......	......	....
Varnish 1877—												
W	IVM	1.66	3.92	5.92	7.58	8.50	9.42	10.12	......	......	......	4.18
F	IVM	1.42	3.00	4.25	5.67	6.25	6.87	7.50	......	......	......	....
Varnish 1875 and spar—												
W	VM	1.17	2.75	4.83	6.33	7.33	8.75	8.83	9.58	10.00	......	5.50
F	VM	1.19	2.50	3.58	5.00	5.75	6.42	6.83	7.17	7.75	......	....
Varnish 1876 and spar—												
W	VIM	1.50	3.50	5.50	6.92	7.75	8.58	9.25	10.00 (75)	......	......	4.82
F	VIM	1.00	2.16	3.17	4.08	4.75	5.25	5.83	6.00	......	......	....
Varnish 1877 and spar—												
W	VIIM	1.33	3.33	5.00	6.58	7.75	8.50	9.16	9.75 (75)	10.25	......	5.68
F	VIIM	1.58	2.66	3.50	4.83	5.42	6.08	6.58	6.75	......	......	....

TEARING TESTS.

In these tests wooden jaws were used, fitted to a Riehle fabric testing machine. The jaws moved apart at a speed of approximately 6 inches per minute.

The Plates I–VI were made by setting up the machine in a dark room, putting the sample under tension, and holding a dry plate against the sample. An electric bulb on the other side of the sample furnishes light for the exposure. In the case of cotton fabrics the small size of the yarn and its transparency gave poor definition; this difficulty was removed by first coloring the sample with a yellow naphtha soluble dye. The photographs are therefore actual size, and show up the conditions of the threads quite clearly.

The factor obtained by dividing the breaking load for a 1-inch cut by that for the uncut fabric gives some idea as to the relative tearing resistance of various materials. This, with the actual tensile, should furnish a good basis for comparing fabrics as to suitability.


Load-Lb per In.- Warp
% Stretch - Warp
Stress-Stretch Curves of High Grade Linen (Warp)
Before and after
Doping and Varnishing

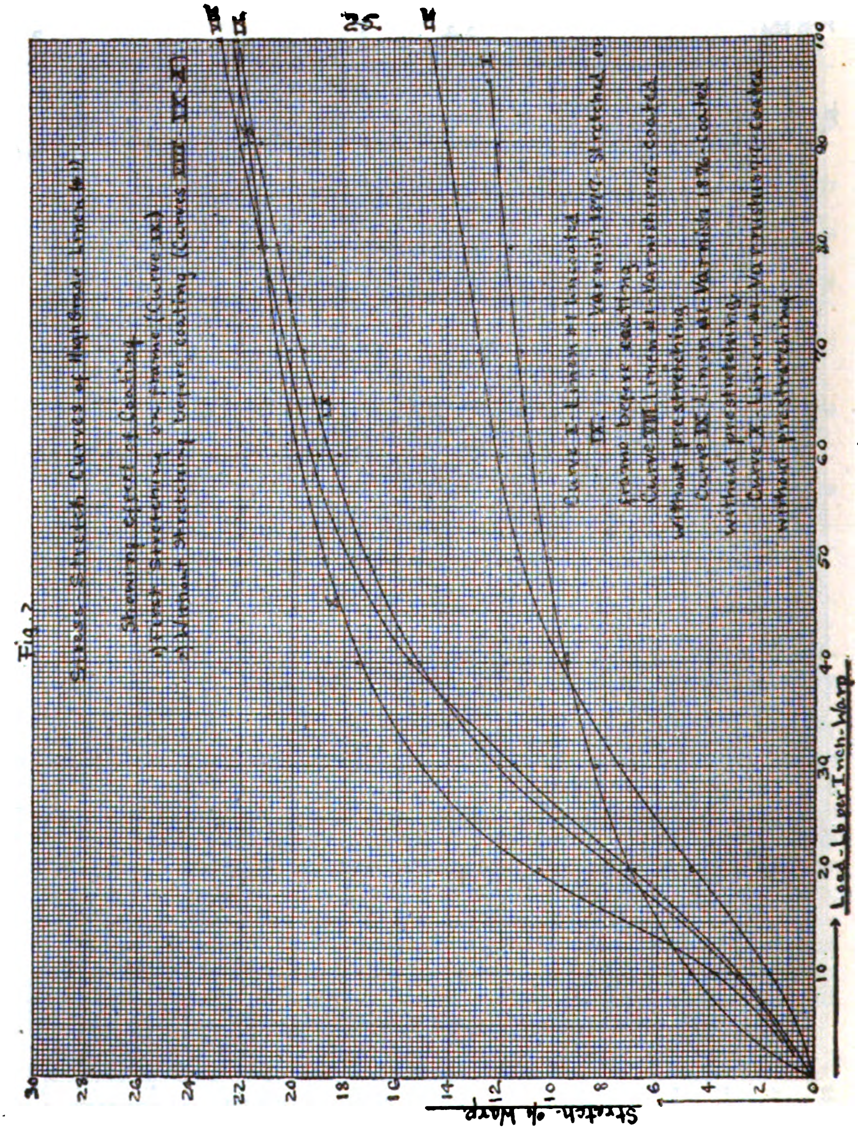


Fig. 7
Load-Lbs per Inch-Warp
Stretch-% Warp

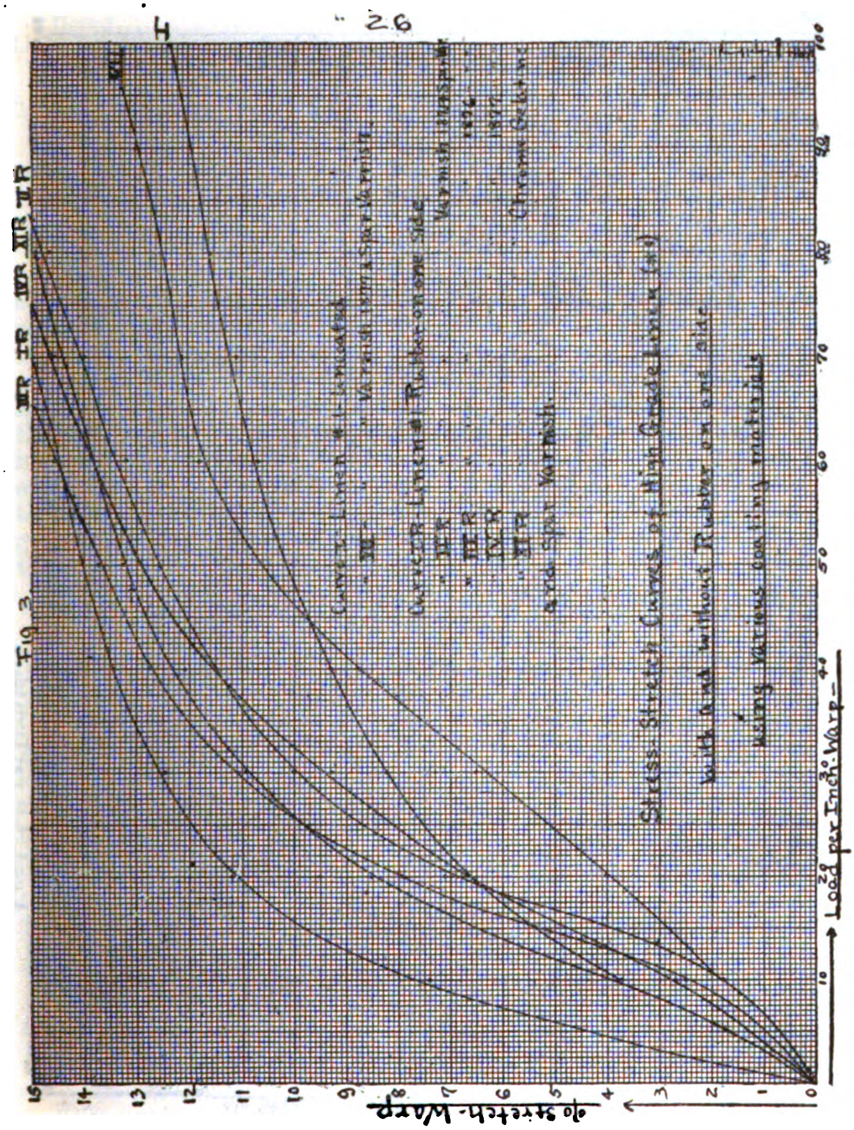
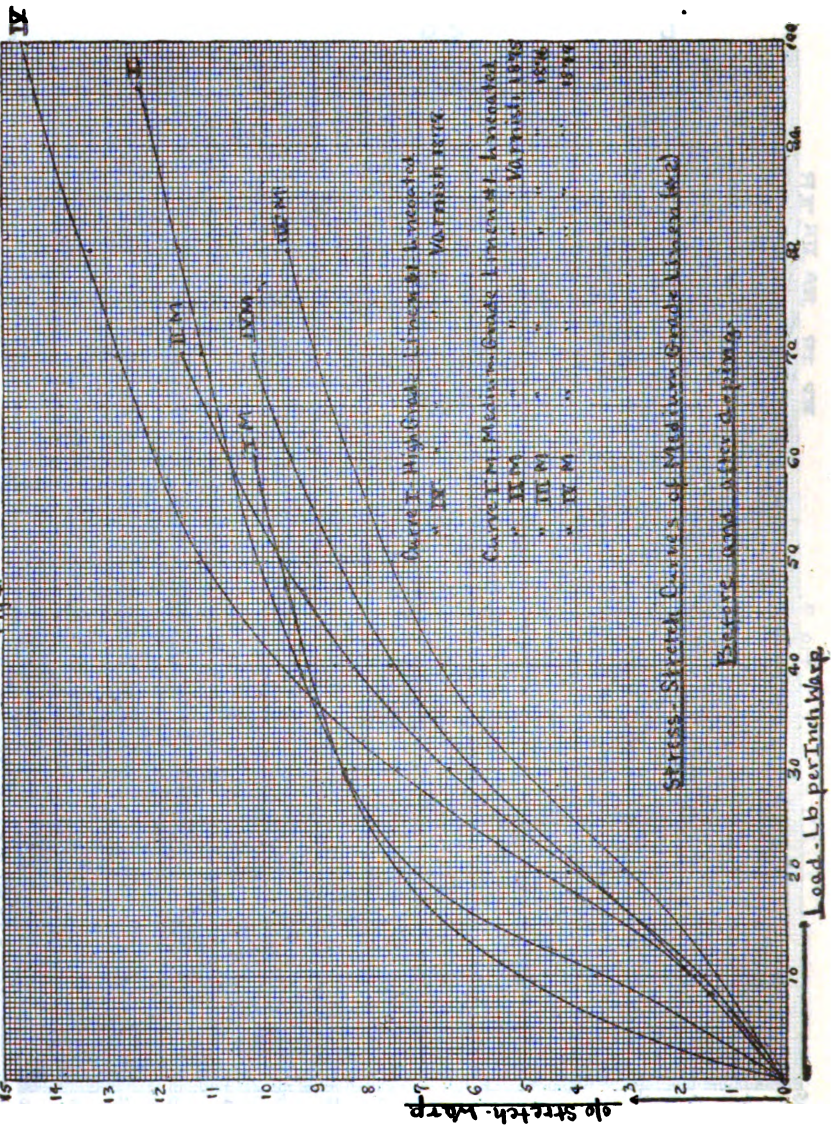


Fig 3
Stress-Stretch Curves of High Grade Linen (a)
with and without Rubber on one side
using various coating materials
Load per Inch. Warp
% Stretch-Warp

Fig 4.

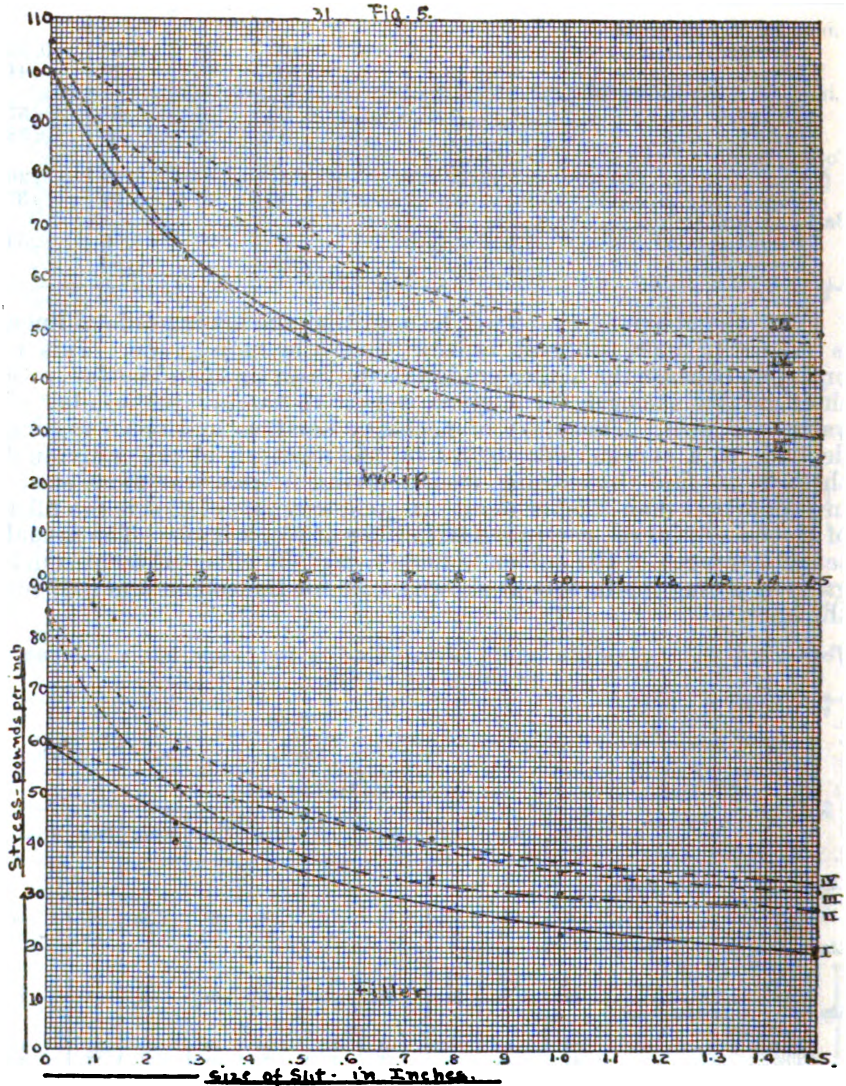

Stress-Stretch Curves of Medium Grade Linen (M2)
Before and after doping
Load. Lb. per Inch Warp
% Stretch. Warp

	Tensile strength (pounds per inch).		Tearing factor.	
	Warp.	Filler.	Warp.	Filler.
Linen No. 1, high grade:				
Uncoated	100	59	0.50	0.52
Doped	106	86	.29	.44
Linen No. 2, medium grade:				
Uncoated	65	45	.67	.57
Doped	85	75	.58	.58
Cotton, light weight:				
Uncoated	37	49½	.48	.36
Doped	45	45	.38	.37
Balloon fabric:				
Double parallel	85	70	.36	.33
Double bias	65	......	.66	......

From the above figures it will be seen that the lower grade of linen is relatively more difficult to tear than the high grade. This is probably because the higher grade fabrics, both linen and cotton, owe their greater strength for a given weight to the greater number of yarns per inch. These are of necessity smaller, and since tearing depends to a considerable extent on the strength of the individual threads, we find that strong, closely woven fabrics tear more easily in proportion than weaker ones. A good example of this is the filler of the cotton fabric, compared with filler of No. 2 linen. The actual tensile strength of the cotton is higher, but the effect of a cut much greater, giving the factors as shown: 0.36 for the cotton and 0.57 for the linen.

Tearing tests on aeroplane and balloon fabrics—Load required to start tear, and to break, for slits of various sizes.

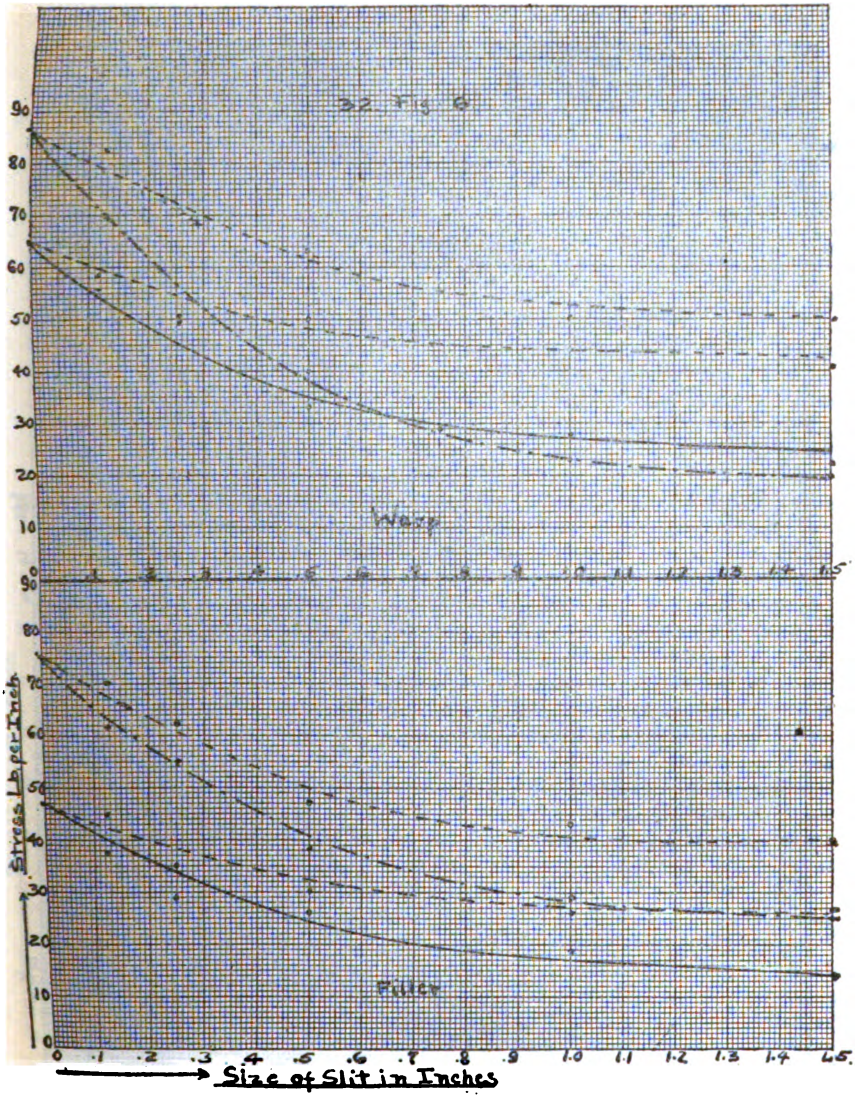
Fabric.	Size slit.									
	0 inch.		¼-inch.		½-inch.		1-inch.		1½-inch.	
	Load per inch.									
	Tear.	Break.	Tear.	Break.	Tear.	Break.	Tear.	Break.	Tear.	Break.
Linen, No. 1, high grade, uncoated:										
Warp	100	100	66½	74	48½	66	36	50	27	49
Filler	59	59	40	44	34	42	23½	31	18	29
Linen, No. 1, high grade, coated, 1875 var.:										
Warp	106	106	74	90	49	70	31	45	26	43
Filler	86	86	51	68½	37½	45½	30	38	27	31
Linen, No. 2, medium grade, uncoated:										
Warp	65	65	49½	51	32	50	28	44	21	42
Filler	45	45	29½	35	26	30	20	26	17	25
Linen, No. 2, medium grade, coated, 1875 var.:										
Warp	85	85	57	74	41	64	23	50	21	49
Filler	75	75	55	62	38	46	29	43½	25	36
Cotton, light weight, uncoated:										
Warp	37	37	16	18	10½	18	10	18	9	18
Filler	49½	49½	18	20	14	18	10	18	(8)	(15)
Cotton, light weight, coated, 1875 var.:										
Warp	45	45	23	26	18½	22	15½	17½	14	18
Filler	45	45	20½	22	15	16½	11½	(17)	11	14½
Balloon fabric, double, parallel:										
Warp	85	85	41	46	30	37	23	31	20	25
Filler	70	70	34	36	23	29½	17½	23½	14	20
Balloon fabric, double bias	65	65	53	57	47	52	30	43	20	34



Tearing Tests on Linen - #1 (High Grade)

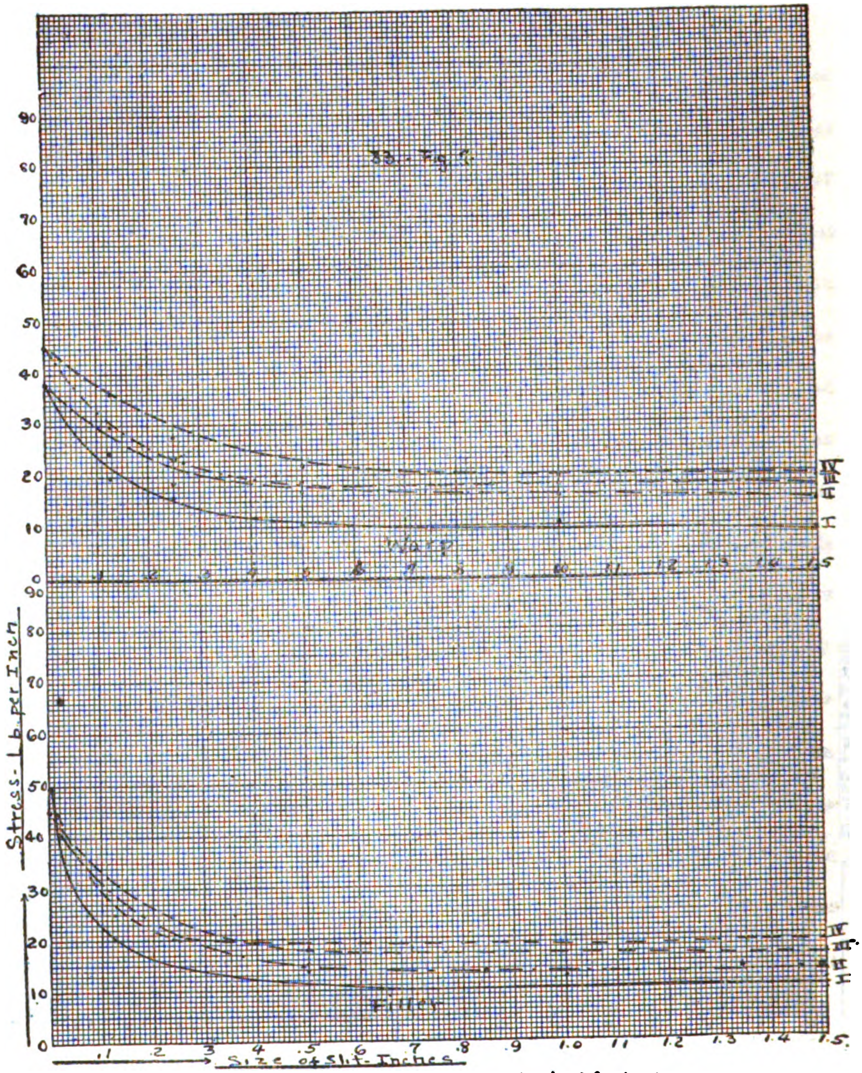
Curve I Tearing Point Undoped
" II " " Doped
" III Breaking " Undoped
" IV " " Doped

——— Tearing Point, Undoped
— —·— " " Doped
------- Breaking Point



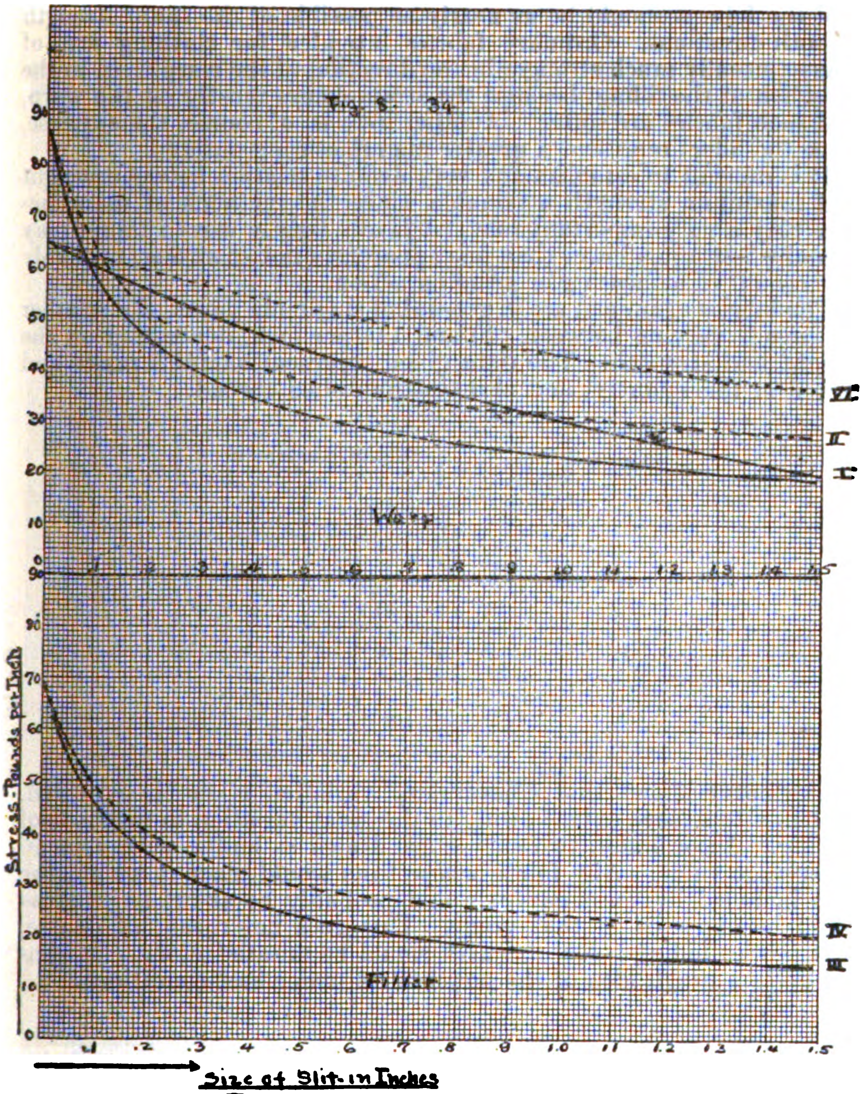
Tearing Tests on Linen #2 (Medium Grade)

Curve I - Tearing Point - Undoped ——— Tearing Point - Undoped
" II - " " Doped —.—.— " " Doped
" III Breaking - Undoped - - - - - - Breaking Point.
" IV " " Doped



Tearing Test on Light Weight (2½ oz) Cotton Fabric

Tearing Point - Undoped
" " Doped
Breaking Point



Tearing Tests on Balloon Fabric.

Curves I & III. Tearing points Double parallel balloon fabric. Warp & filler resp.
" II & IV. Breaking " " " " " " " "
" V & VI Tearing and Breaking Points. " " Double bias.

COTTON FABRICS.

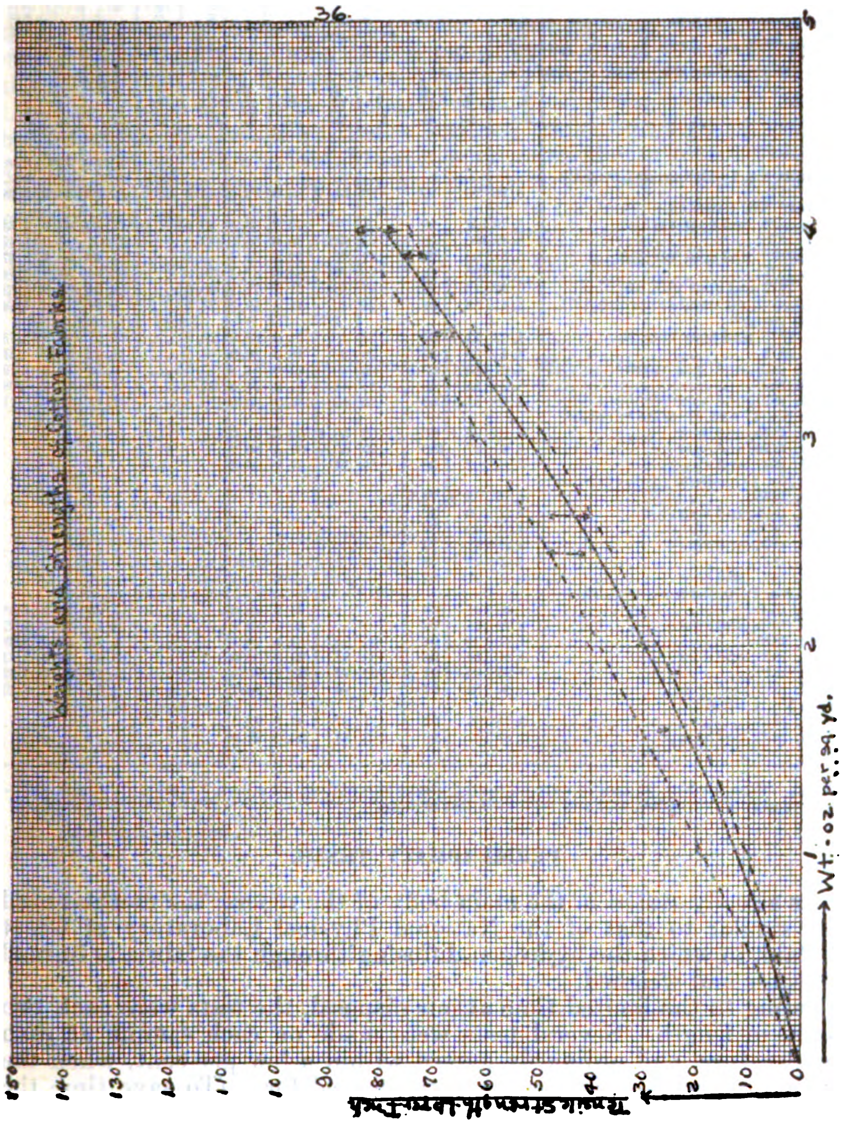
Sea island or Egyptian cotton, preferably the former, should be used for fabrics intended for use in making balloon fabric. In general the fabrics should be as nearly as possible of the same strength in both directions. Ordinary fabrics intended for clothing are, of course, usually much stronger in the direction of the warp than in the direction of the filling, because the strain comes mostly on the warp, and such fabrics are softer. Another item is, of course, the expense, since the fillers represent a greater manufacturing outlay.

It is difficult to establish any very definite relation between weight and maximum strength attainable, since the methods of manufacture play a very important rôle. A heavy tightly woven fabric may actually test much lower than one apparently not so strong, probably on account of a shearing or grinding action.

The fabrics examined are in general of single-ply yarns, the number of threads varying between 120 and 144 per inch, depending on the weight and strength. The data given represent samples made and tested in this country, and also test published abroad.

	Weight (ounces per square yard).	Strength (pounds per inch).	
		Warp.	Filler.
I	1.60	27.0	26.0
II	1.85	24.3	24.5
III	1.98	31.0	31.0
IV	2.44	41.5	49.0
V	2.67	40.9	49.2
VI	3.51	70.0	67.0
VII	3.86	72.0	75.0
VIII	4.05	81.0	78.0

The curve shows that considerable variation is to be expected, probably to a large extent owing to the great variation in methods of testing. Accordingly, two curves are drawn as limits, with a mean or average value. Any fabric whose tests would place it within the area included by these curves would probably be about as good as could be expected in that grade. This does not mean, of course, that fabrics falling below this area would be unsatisfactory. It simply gives a rough idea of the possibilities under best conditions.


Weights and Strengths of Cotton Fabrics
Wt. - oz. per sq. yd.
0
1
2
3
4
5
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
36

Summary of various tests on aeroplane fabrics.

Fabric.	Weight (ounces per square yard).	Tensile strength (pounds per inch). Original. Warp.	Tensile strength (pounds per inch). Original. Filler.	Tensile strength (pounds per inch). After 3 weeks' exposure. Warp.	Tensile strength (pounds per inch). After 3 weeks' exposure. Filler.	Effect of exposure (per cent strength of original.) Warp.	Effect of exposure (per cent strength of original.) Filler.	Fire test. Seconds to burn 3½ feet.	Fire test. Distance burned.	Water absorption. In saturated atmosphere.	Water absorption. Soaking.	Loss in weight from soaking.
									Inch.	*Per cent.*	*Per cent.*	*Per cent.*
1. Linen No. 1 (high grade), varnish, 1875	5.18	95	92	62	66.7	65.0	72.5	35.0	.....	12.94	44.2	3.96
Linen No. 1 varnish:												
2. 1875, and spar varnish	5.88	101	90	75	72	74.2	80.0	33.6	.....	12.90	43.6	3.33
3. 1876	5.49	100	88	68	57	68.0	65.0	23	.....	10.01	43.6	5.47
4. 1876, and spar varnish	6.18	98	92	71	70	72.8	76.5	22.6	.....	11.49	38.2	3.27
5. 1877	5.24	106	91	90	75	84.8	82.5	38.3	.....	13.74	51.9	3.94
6. 1877 and spar varnish	6.42	113	83	81	59	71.7	71.2	39.6	.....	12.14	60.9	4.03
7. Cotton (light weight) varnish, 1875	3.45	58	68	28	40	48.4	59.3	23.0	.....	8.7	32.4	.84
Cotton varnish:												
8. 1875, and spar varnish	4.62	51	59	38	40	74.0	68.0	20.6	.....	6.27	45.0	.75
9. 1876	3.43	50	62	24	23	48.5	36.6	9.6	.....	6.42	37.9	.31
10. 1876, and spar varnish	4.07	55	63	29	40	49.8	63.2	10.0	.....	5.06	34.3	.79
11. 1877	3.24	51	59	44	44	87.2	74.2	22.0	.....	8.03	40.0	.96
12. 1877, and spar varnish	4.18	51	53	43	43	85.2	82.0	18.3	.....	7.41	42.1	.71
Linen No. 1, Am. chloride varnish:												
13. 1875, and spar	7.16	97	95½	52	58.4	53.5	61.0	.....	1.6	.....	.....	.....
14. 1876, and spar	6.90	117	100	79	60.2	67.5	60.2	.....	1.3	.....	.....	.....
15. 1877, and spar	7.57	107	96	58	54	54.2	56.3	.....	1.4	.....	.....	.....
Linen No. 2 (medium grade) varnish:												
16. 1875	4.17	88.8	74.9	.....	.....	.....	.....	.....	.....	.....	.....	.....
17. 1875, and spar	5.50	100	86	.....	.....	.....	.....	.....	.....	.....	.....	.....
18. 1876	4.15	92	79	.....	.....	.....	.....	.....	.....	.....	.....	.....
19. 1876, and spar	5.50	91	77	.....	.....	.....	.....	.....	.....	.....	.....	.....
20. 1877	4.23	78	78	.....	.....	.....	.....	.....	.....	.....	.....	.....
21. 1877, and spar	5.39	91	82	.....	.....	.....	.....	.....	.....	.....	.....	.....
Linen No. 1 (rubberized) varnish:												
22. 1875	7.37	121	104	.....	.....	79.2	75.0	.....	.....	7.73	63.5	4.34
23. 1875, and spar	8.44	116	99	.....	.....	89.0	86.0	.....	.....	8.18	39.4	3.27
24. 1876	7.63	120	94	96	78	87.5	78.7	.....	.....	8.53	44.3	3.38
25. 1876, and spar	8.89	119	96	103	85	94.5	100.0	.....	.....	10.69	38.9	2.82
26. 1877	7.57	119	91	105	74	93.2	95.5	.....	.....	8.32	55.3	5.92
27. 1877, and spar	8.94	119	97	113	96	96.5	86.7	.....	.....	6.04	39.0	5.23
Linen No. 1 varnish:												
28. 1875	5.18	95	92	111	87	89.5	92.3	.....	.....	.....	.....	.....
29. 1875, and spar	5.88	101	90	115	84	90.0	91.0	.....	.....	.....	.....	.....

NOTE.—Samples Nos. 22 and 29 were exposed 2 weeks to weather; all others, 3 weeks. Varnish, 1876—cellulose nitrate; varnishes, 1875 and 1877—cellulose acetate.

PERMEABILITY TESTS.

As already stated in the main body of the report, the method used was similar to that of the National Physical Laboratory of Great Britain, in which the hydrogen diffusing through the fabric is burned to water and weighed.

Owing to the limited time at our disposal, the tests were each two hours in length. Several tests were made on each sample at each temperature, and ordinarily agreed within a few per cent, when the slight temperature differences were allowed for. (To save time the thermostat was not run always at the same temperature, but simply kept constant at one temperature for each run. As the room temperature varied greatly from day to day during the period in which the tests were made, this made the operation of the thermostat more simple, and in addition gave in many cases a further check on the temperature effect.)

The diameter of the cell was 220 millimeters.

The hydrogen was run through one side of the cell at a rapid rate for several hours at the start of an experiment, to insure the expulsion of air. The proper rate for the passage of the air was found by experiment; it was noted that above a certain point, even with increased absorption apparatus, the total weight of water absorbed did not increase, indicating that the hydrogen was swept out practically as soon as it entered the cell. In the interval between tests on the same fabric, the air side was continually swept out, to prevent the accumulation of hydrogen on the air side. For this purpose a three-way stop-cock was introduced, and connections with trap-bottles made so that the furnace and cell could be swept out separately with air. It was found that in some cases the furnace contained small amounts of moisture that had not been all removed during the experiment, so at the expiration of the time by turning the cock the cell was swept out in preparation for the next run, while dry air was drawn from without through the furnace and absorption tubes for 10 to 15 minutes.

Specimen tests are shown.

Permeability tests on various fabrics.

Fabric.	Temperature (° C.).	Permeability (liters per square meter per 24 hours, at 760/0°).
No. 1 balloon fabric, 2-ply parallel (9.25 ounces per square yard):		
1.65 ounces per square yard rubber between plies	21.2	54.99
1 ounce per square yard rubber on inside face	22.07	56.37
	29.68	63.4
	30.01	65.3
	40.08	79.1
	40.09	79.4
No. 2 balloon fabric, 2-ply parallel (10.81 ounces per square yard):		
3.11 ounces per square yard rubber between plies	20.45	11.64
1 ounce per square yard rubber on inside face	21.65	11.29
	29.87	16.8
	30.71	17.32
	32.27	18.79
	33.58	24.35
	39.19	26.34
No. 3 balloon fabric, 2-ply parallel (93.2 ounces per square yard):		
5.51 ounces per square yard rubber between plies	20.04	11.2
1 ounce per square yard rubber on inside face	20.23	11.7
	39.48	25.25
	30.63	25.55
	40.14	26.37
Balloon cloth No. 3, 4 coats varnish No. 1876 on cloth (about 2 ounces per square yard)	21.42	10.86
	21.91	11.8
	22.00	11.34
	29.99	15.44
	31.68	17.11
	40.51	24.73
	40.75	25.25
Balloon cloth No. 3, 4 coats varnish No. 1877 on cloth (about 2 ounces per square yard)	20.81	11.13
	20.85	11.34
	21.28	11.5
	30.51	16.90
	30.57	17.15
	39.09	24.13
	39.74	24.22
Balloon cloth No. 3, gelatin compound on rubber (2 ounces per square yard)	20.2	1.4
	20.01	.8
	21.29	1.4
	38.91	5.6
	38.95	6.6
Balloon fabric No. 3, varnish No. 1876 (2 ounces per square yard), on rubber	20.03	4.5
	20.22	5.0
	20.46	5.6
	38.96	10.2
	39.24	11.2

Permeability tests on various fabrics—Continued.

Fabric.	Temperature (° C.).	Permeability (liters per square meter per 24 hours, at 760/0°).
Balloon cloth No. 3, varnish No. 1877 (2 ounces per square yard), on rubber.....	19.91	4.55
	20.25	4.15
	37.45	10.85
	38.90	11.35
	38.96	12.7
Balloon cloth No. 19 (12 ounces per square yard)................................	20.3	11.2
	21.1	11.37

(1) It will be noted that gelatin compound gives very low permeability. The use of gelatin on fabric for balloons was suggested by Julhe.[1] Austerweil tried this and found [2] that at first there was practically no loss in volume, even a slight gain due to gases dissolved in the water. After 35 hours the membrane was apparently saturated and lost gas at practically the same rate as the comparison rubber membrane. On the other hand, although each of our tests was only two hours long, the total time in which the cell was filled with hydrogen, and the gelatin-rubber fabric in place, was 48 hours, yet at the end of that time, when the tests were made at 40° C., the permeability was only one-fourth that of the rubberized fabric alone. It is possible that in contact with dry rubber and dry gases, as in our apparatus, the membrane might act differently.

(2) Another point of interest is the test on fabrics 2 and 3 compared with fabric 19. The first two were experimental samples, and for convenience made parallel. The fabric 19 was bias, yet showed practically no difference in permeability. There has been some indication in tests made at the National Physical Laboratory that parallel fabrics were much more permeable. They state that probably the method of manufacture has a considerable effect. This has not been noticed in our tests, and the reason for any such difference is not apparent.

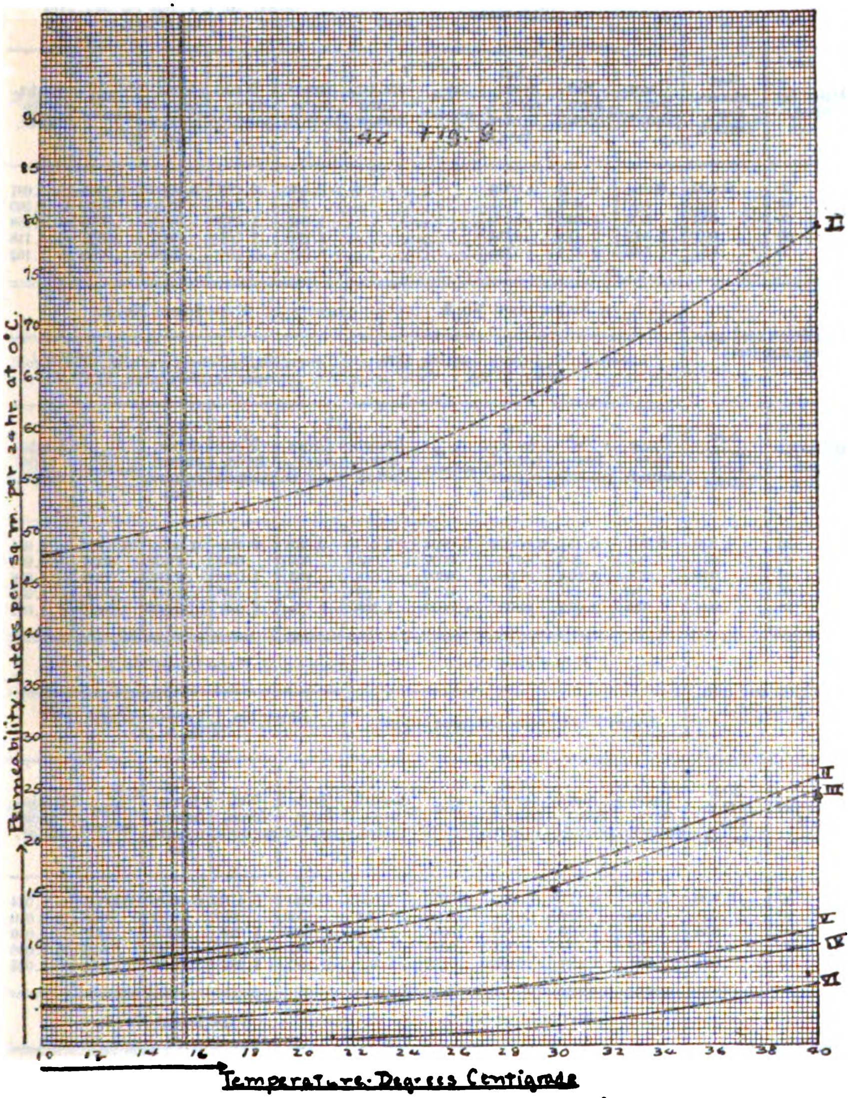
(3) *Temperature coefficient.*—This varies with the temperature and degree of permeability of the material. From our experiments we found the following values:

	Rate of increase at—		
	10–20° C.	20–30° C.	30–40° C.
	Per cent.	*Per cent.*	*Per cent.*
Rubber fabric, permeability at 15° C..................................	4.4	4.6	4
Rubber fabric coated with 2-ounce gelatin on rubber................	....	1.3	3.4

(4) *Effect of Weathering.*—On account of the limited time at our disposal for making this investigation, long weathering tests on these samples were not made. Aging by continuous exposure for one month caused no increase in permeability; in fact, one of our samples seemed improved. The rubber layers were apparently unaffected, so this improvement was not due to resinification which has been noted in England, but was more likely due to a slight variation in samples.

[1] C. R. Acad. Sc., 1912, Feb. 12.

[2] Die Angewandte Chemie in der Luftfahrt, p. 90.



Effect of Temperature on Permeability.

I Balloon Fabric. 1.65 oz. Rubber between plies
II " " (a) 3.11 & 5.51 oz " " "
III " " 5.51 oz rubber. Coated on cloth. with Aerovarnish. 2 oz
IV-V " " " " " " " rubber " " 10% Ditto. 4 oz
VI. " " " " " " " " " gelatine compound. 2 oz

Surface friction of aeronautic fabrics at different wind velocities.

Condition and area (square feet).		Experiment No. 1. Plate glass.					Experiment No. 2. Linen No. 1, 1 coat varnish, 1876 (area, 50.35).				
Miles per hour.	Net correction, pound.	Gross force, pounds.	Net force, pounds.	Net force, pound, square foot.	Net excess.	Resistance factor.	Gross force, pounds.	Net force, pounds.	Net force, pound, square foot.	Net excess.	Resistance factor.
30	0.020	0.384	0.404	0.0079	0	0	0.408	0.428	0.0085	0.0006	1.081
40	.031	.637	.668	.0131	....	....	.679	.710	.0141	.0010	1.080
50	.046	.969	1.015	.0199	....	....	1.046	1.092	.0218	.0019	1.098
60	.071	1.342	1.413	.0276	....	....	1.480	1.551	.0309	.0023	1.118
70	.094	1.768	1.862	.0364	....	....	2.040	2.134	.0424	.0060	1.163

Condition and area (square feet).		Experiment No. 3. Linen No. 1, 3 coats varnish, 1876 (area, 50.35).					Experiment No. 4. Linen No. 1, 3 coats varnish, 1876; 1 coat spar varnish (area, 50.35).				
Miles per hour.	Net correction, pound.	Gross force, pounds.	Net force, pounds.	Net force, pound, square foot.	Net excess.	Resistance factor.	Gross force, pounds.	Net force, pounds.	Net force, pound, square foot.	Net excess.	Resistance factor.
30	0.020	0.394	0.414	0.00822	0.0003	1.042	0.389	0.409	0.0081	0.0002	1.031
40	.031	.665	.696	.0138	.0007	1.060	.649	.680	.0135	.0004	1.034
50	.046	.998	1.044	.0208	.0009	1.048	.981	1.027	.0204	.0005	1.028
60	.071	1.410	1.481	.0295	.0019	1.067	1.376	1.447	.0287	.0011	1.038
70	.094	1.919	2.013	.0403	.0039	1.108	1.854	1.948	.0387	.0023	1.061

Condition and area, (square feet).		Experiment No. 5. Linen No. 1, uncoated (area, 50.18).					Experiment No. 6. Linen No. 1, 3 coats varnish, 1877 (area, 50.18).				
Miles per hour.	Net correction, pound.	Gross force, pounds.	Net force, pounds.	Net force, pound, square foot.	Net excess.	Resistance factor.	Gross force, pounds.	Net force, pounds.	Net force, pound, square foot.	Net excess.	Resistance factor.
30	0.020	0.457	0.477	0.0095	0.0016	1.205	0.390	0.410	0.0082	0.0003	1.034
40	.031	.778	.810	.0161	.0030	1.234	.652	.683	.0136	.0005	1.040
50	.046	1.204	1.250	.0249	.0050	1.254	.988	1.034	.0206	.0007	1.039
60	.071	1.738	1.809	.0361	.0085	1.305	1.392	1.463	.0292	.0016	1.056
70	.094	2.395	2.489	.0496	.0132	1.362	1.890	1.984	.0395	.0031	1.085

Condition and area (square feet).		Experiment No. 7. Linen No. 1, 3 coats varnish, 1877; 1 coat spar varnish (area, 50.18).					Experiment No. 8. Linen No. 1, 3 coats varnish, 1877; 2 coats spar varnish (area, 50.18).				
Miles per hour.	Net correction, pound.	Gross force, pounds.	Net force, pounds.	Net force, pound, square foot.	Net excess.	Resistance factor.	Gross force, pounds.	Net force, pounds.	Net force, pound, square foot.	Net excess.	Resistance factor.
30	0.020	0.393	0.413	0.0082	0.0003	1.044	0.393	0.413	0.0082	0.0003	1.044
40	.031	.655	.686	.0137	.0006	1.049	.644	.675	.0134	.0003	1.026
50	.046	.977	1.023	.0204	.0005	1.028	.978	1.024	.0204	.0005	1.028
60	.071	1.384	1.455	.0288	.0012	1.041	1.367	1.438	.0286	.0010	1.033
70	.094	1.884	1.978	.0394	.0030	1.081	1.874	1.968	.0392	.0028	1.078

Surface friction of aeronautic fabrics at different wind velocities—Continued.

Condition and area (square feet).		Experiment No. 9. Balloon fabric No. 3, double par. cloth outside (area, 49.6).					Experiment No. 10. Balloon fabric No. 3 (same as 9), freshly singed (area, 49.6).				
Miles per hour.	Net correction, pound.	Gross force, pounds.	Net force, pounds.	Net force, pound, square foot.	Net excess.	Resistance factor.	Gross force, pounds.	Net force, pounds.	Net force, pound, square foot.	Net excess.	Resistance factor.
30	0.020	0.672	0.692	0.0139	0.0060	1.766	0.493	0.513	0.0103	0.0024	1.311
40	.031	1.149	1.180	.0238	.0107	1.822	.883	.914	.0184	.0053	1.406
50	.046	1.764	1.810	.0365	.0166	1.838	1.403	1.449	.0292	.0093	1.470
60	.071	2.501	2.573	.0518	.0242	1.878	2.041	2.112	.0426	.0150	1.539
70	.094	3.452	3.546	.0715	.0351	1.965	2.898	2.992	.0603	.0239	1.664

Condition and area (square feet).		Experiment No. 11. Balloon fabric No. 3 (same as 10); 1 coat varnish, 1876 (area, 49.6).					Experiment No. 12. Balloon fabric No. 3 (same as 10); 3 coats varnish, 1876 (area, 49.6).				
Miles per hour.	Net correction, pound.	Gross force, pounds.	Net force, pounds.	Net force, pound, square foot.	Net excess.	Resistance factor.	Gross force, pounds.	Net force, pounds.	Net force, pound, square foot.	Net excess.	Resistance factor.
30	0.020	0.446	0.466	0.0094	0.0015	1.180	0.394	0.414	0.0083	0.0004	1.056
40	.031	.783	.814	.0164	.0083	1.253	.661	.692	.0139	.0008	1.063
50	.046	1.199	1.245	.0251	.0052	1.264	1.009	1.055	.0213	.0014	1.072
60	.071	1.722	1.793	.0362	.0086	1.309	1.419	1.490	.0300	.0024	1.082
70	.094	2.332	2.426	.0490	.0126	1.345	1.904	1.998	.0403	.0039	1.107

Condition and area (square feet).		Experiment No. 13. Balloon fabric No. 3, bias (area, 48.88).					Experiment No. 14. Balloon fabric No. 3, bias, freshly singed (area, 48.88).				
Miles per hour.	Net correction, pound.	Gross force, pounds.	Net force, pounds.	Net force, pound/square foot.	Net excess.	Resistance factor.	Gross force, pounds.	Net force, pounds.	Net force, pound/square foot.	Net excess.	Resistance factor.
30	0.020	0.631	0.651	0.0133	0.0054	1.691	0.483	0.503	0.0103	0.0024	1.308
40	.031	1.078	1.109	.0227	.0096	1.739	.864	.895	.0183	.0052	1.402
50	.046	1.632	1.678	.0343	.0144	1.728	1.461	1.507	.0309	.0110	1.555
60	.071	2.343	2.414	.0494	.0218	1.782	2.157	2.228	.0457	.0181	1.651
70	.094	3.294	3.388	.0694	.0330	1.902	3.043	3.137	.0642	.0278	1.762

Condition and area (square feet).		Experiment No. 15. Balloon fabric No. 6, double bias, special fabric (area, 49.34).					Experiment No. 16. Balloon fabric No. 6, double bias, special fabric, freshly singed (area, 49.34).				
Miles per hour.	Net correction, pound.	Gross force, pounds.	Net force, pounds.	Net force, pound/square foot.	Net excess.	Resistance factor.	Gross force, pounds.	Net force, pounds.	Net force, pound/square foot.	Net excess.	Resistence factor.
30	0.020	0.468	0.488	0.0099	0.0020	1.252	0.423	0.443	0.0099	0.0020	1.130
40	.031	.858	.889	.0180	.0049	1.378	.744	.775	.0157	.0026	1.202
50	.046	1.343	1.389	.0281	.0082	1.414	1.170	1.216	.0247	.0048	1.243
60	.071	1.959	2.030	.0412	.0136	1.490	1.744	1.815	.0368	.0092	1.331
70	.094	2.648	2.742	.0556	.0202	1.528	2.378	2.472	.0500	.0136	1.372

Surface friction of aeronautic fabrics at different wind velocities—Continued.

Condition and area (square feet).		Experiment No. 21. Aeroplane fabric, rubberized, No. 23 (area, 48.8).					Experiment No. 22. Aeroplane fabric, aluminum coated, No. 24 (area, 48.6).				
Miles per hour.	Net correction, pound.	Gross force, pounds.	Net force, pounds.	Net force, pound/square foot.	Net excess.	Resistance factor.	Gross force, pounds.	Net force, pounds.	Net force, pound/square foot.	Net excess.	Resistance factor.
30	0.020	0.382	0.412	0.0084	0.0005	1.070	0.394	0.414	0.0085	0.0006	1.078
40	.031	.653	.690	.0142	.0011	1.082	.657	.688	.0142	.0011	1.083
50	.046	1.004	1.050	.0215	.0016	1.083	.988	1.034	.0213	.0014	1.073
60	.081	1.379	1.460	.0299	.0023	1.081	1.375	1.456	.0299	.0023	1.081
70	.094	1.824	1.918	.0393	.0029	1.079	1.856	1.950	.0401	.0037	1.101

SURFACE FRICTION TESTS.

In the next to the last column of each experiment, pages 43–4, are given under the heading "Net excess" the numerical difference between the resistance in pounds per square foot of the material, and the resistance of plate glass. In the last column are given factors obtained by dividing the resistance of the material by that of glass at the same velocity.

In general the resistance of an object to the wind increases with the square of the velocity. The general form is, for unit area:

$$P = K V^2.$$

When P = pressure.
V = velocity.
K = a constant.

It has been found by Froude and others that surface friction varies with about the 1.87 power of the velocity.

Plotting the logarithms of the velocity against the pressure, we obtained from our results, in practically all cases, a straight line. The values at 70 miles per hour were a little off in most cases, indicating the pressure of another factor, possibly due to temperature.

The logarithms were plotted and from the values of the faired curves, the approximate exponents and coefficients were obtained algebraically for some of the most interesting cases.

$$\text{General equation } P = K V^n.$$

When P = pressure in pounds per square foot.
V = velocity in miles per hour.
n and K = constants.

	K	N
Experiment 1. Plate glass	0.0000178	1.84
Experiment 2. Linen No. 1, varnish No. 1876	.0000156	1.85
Experiment 5. Linen No. 1, uncoated	.0000137	1.92
Experiment 9. Balloon fabric No. 3	.0000192	1.93

It will be noted that in general the rougher materials have higher exponents, approaching 2 in the case of balloon fabric.

Absorption tests, balloon and aeroplane fabrics.

Fabric.	Atmospheric weight.	Dry weight.	Moist weight.	Normal moisture.		Moisture after suspension in saturated atmosphere.		Atmospheric weight.	Dry weight.	Wet weight.	Dry weight after soaking.	Normal moisture.		Water held in fabric after soaking.		Weight of material removed by soaking.	
				Ounces.	Per cent.	Ounces.	Per cent.					Ounces.	Per cent.	Ounces.	Per cent.	Ounces.	Per cent.
High-grade linen No. 1, untreated, weight 4.6 ounces:																	
Varnish 1875 (cell. acetate)	5.52	5.18	5.85	0.34	6.56	0.67	12.94	5.65	5.30	7.34	5.09	0.35	6.61	2.25	44.2	0.21	3.96
Varnish 1875 and spar varnish	6.26	5.88	6.57	.38	6.46	.69	12.90	6.09	5.71	7.93	5.52	.38	6.65	2.41	43.6	.19	3.33
Varnish 1876 (cell. nitrate)	5.71	5.49	6.04	.22	4.02	.55	10.01	5.71	5.49	7.45	5.19	.22	4.02	2.26	43.6	.30	5.47
Varnish 1876 and spar varnish	6.54	6.18	6.89	.36	5.83	.71	11.49	6.46	6.11	8.17	5.91	.35	5.44	2.26	38.2	.20	3.27
Varnish 1877 (cell. acetate)	5.61	5.24	5.96	.37	7.07	.72	13.74	5.72	5.34	7.79	5.13	.38	7.13	2.66	51.9	.21	3.94
Varnish 1877 and spar varnish	6.87	6.42	7.20	.45	7.01	.78	12.14	6.64	6.20	9.57	5.95	.44	7.10	3.62	60.9	.25	4.03
Rubberized (one side)	6.49	6.27	7.08	.22	3.51	.59	9.41	6.63	6.41	9.88	6.16	.22	3.43	3.72	60.4	.25	3.90
Rubberized, varnish 1875	7.63	7.37	8.20	.26	3.53	.57	7.73	7.62	7.36	11.51	7.04	.26	3.53	4.47	63.5	.32	4.34
Rubberized, varnish 1875 and spar varnish	8.80	8.44	9.49	.36	4.27	.69	8.18	8.82	8.56	11.54	8.28	.26	3.03	3.26	39.4	.28	3.27
Rubberized, varnish 1876	7.85	7.63	8.50	.22	2.89	.65	8.53	7.89	7.69	10.72	7.43	.20	2.61	3.29	44.3	.26	3.38
Rubberized, varnish 1876 and spar varnish	9.13	8.89	10.08	.24	2.70	.95	10.69	8.82	8.51	11.49	8.27	.31	3.64	3.22	38.9	.24	2.82
Rubberized, varnish 1877	7.83	7.57	8.46	.26	3.43	.68	8.82	7.81	7.60	11.10	7.15	.21	2.76	3.95	55.3	.45	5.92
Rubberized, varnish 1877 and spar varnish	9.23	8.94	9.77	.29	3.25	.54	6.04	9.19	8.85	11.69	8.14	.34	3.84	3.28	39.0	.44	5.28
Cotton (light weight):																	
Varnish 1875	3.74	3.45	3.75	.29	8.40	.30	8.70	3.89	3.58	4.70	3.55	.31	8.67	1.15	32.4	.03	.84
Varnish 1875 and spar varnish	4.86	4.62	4.91	.24	5.19	.29	6.27	4.20	3.99	5.74	3.96	.21	5.27	1.78	45.0	.03	.75
Varnish 1876	3.60	3.43	3.65	.17	4.96	.22	6.42	3.36	3.20	4.40	3.19	.16	5.00	1.21	37.9	.01	.31
Varnish 1876 and spar varnish	4.28	4.07	4.30	.21	5.16	.23	5.66	3.98	3.79	5.05	3.76	.19	5.02	1.29	34.3	.03	.79
Varnish 1877	3.46	3.24	3.50	.22	6.80	.26	8.03	3.35	3.13	4.34	3.10	.22	7.03	1.24	40.0	.03	.96
Varnish 1877 and spar varnish	4.47	4.18	4.49	.29	6.94	.31	7.41	4.59	4.29	6.01	4.23	.30	7.00	1.78	42.1	.03	.71
Balloon fabric, cloth outside (1½-ounce double bias), No. 3	11.35	10.98	11.62	.37	3.37	.64	5.83	11.35	10.68	14.52	....	.37	3.37	3.54	32.8	....	....
Balloon fabric No. 3 and balloon fabric No. 3 spot proof	11.60	11.30	11.76	.30	2.68	.46	4.07	11.38	11.05	13.92	....	.33	3.00	2.87	24.8	....	....
Balloon fabric No. 3, proof No. 123	12.37	11.95	12.20	.42	3.52	1.25	10.50	12.28	11.89	15.20	....	.39	3.28	3.31	27.8	....	....

REPORT No. 6.

PART 2.

SKIN FRICTION OF VARIOUS SURFACES IN AIR.

By Willis A. Gibbons.

INTRODUCTION.

The relation of skin friction or surface friction, to the relative velocity of a surface and the surrounding medium, and the variation of this relation with the nature of the surface is of growing importance to the science of aeronautics. Owing to the greater speeds now developed in air craft of all kinds, it was decided to investigate these relations with particular reference to the sort of surfaces which would be used in aeronautic work.

W. Froude[1] measured the resistance for various surfaces of various lengths in a water channel, and the results of his experiments lead to the following conclusions:

1. The force tangential to the plane due to skin friction, ordinarily varies according to the 1.85–2 power of the velocity for smooth surfaces. For rougher surfaces, it varies practically as the square of the velocity.

2. The length of the plane has a decided effect on the average resistance per unit area, the resistance decreasing as the length increases.

3. Smooth surfaces do not necessarily increase according to a lower power of the velocity than *rougher* surfaces, although the numerical value of the resistance per unit area is less.

4. The index decreases as the length increases for smooth surfaces.

Zahm[2] measured the resistance due to surface friction of planes in a current of air, and found that all smooth surfaces showed an increase in resistance according to the 1.85 power of the velocity. Buckram with 16 threads per inch gave a high resistance and an index of 2.05, practically 2.

He measured the resistance of planes of various lengths and obtained the following equation connecting the length of a plane with its velocity and surface friction:

$$P \propto L^{-.07} V^{1.85} \tag{1}$$

When V = Velocity in feet per second.
L = Length of planes.
p = Tangential force per square foot.

[1] British Assoc. Report, 1872, 118; 1874, 249.
[2] Phil. Mag., VIII, 58–66 (1904).

Lanchester[1] shows that to express the resistance of a plane bringing into account the linear size and kinematic viscosity, we have the relation—

$$R \propto v^{q} L^{1} V^{r} \tag{2}$$

When $q+r=2$
$v=$ Kinematic viscosity.
$L=$ Linear size.
$V=$ Velocity.

The kinematic viscosity[2] $v=\frac{\mu}{\rho}$

When $\mu=$ Coefficient of viscosity.
$\rho=$ Density.

The kinematic resistance, $R=\frac{F}{\rho}$, i. e., it is the resistance per unit density.

Lanchester points out that in terms of R, Zahm's equation (1) becomes

$$R \propto L^{1.93} V^{1.85} \tag{3}$$

whereas according to (2) L and V should have the same index. He adopts the following for a smooth surface.

$$R \propto v^{.1} L^{1.9} V^{1.9} \tag{4}$$

Assuming, what we have found to be the case, that the exponent varies with the nature of the surface, we may put this in the form

$$R \propto v^{2-n} L^{n} V^{n} \tag{5}$$

whence

$$F = \kappa \rho v^{2-n} L^{n} V^{n} \tag{6}$$

For any one surface it is convenient to neglect the length, and embody this and the ρ and v values in one constant, so we have.

$$F = KV^{n} \tag{7}$$

The value of K depends of course on the units.—throughout this paper F will be in lbs. per square feet, and V in miles per hour. The value of .1 for air is 1.3 times that for water, so this and the relative densities give a means of calculating from one medium to the other.

The values of n and K vary with the surface even for so-called smooth surfaces, and as will be shown, seem in such cases to bear a more or less definite relation to each other.

[1] Tech. Rept. Adv. Com. for Aeronautics, 1909-10, p. 34.

[2] Lanchester's Aerodynamics, p. 36.

EXPERIMENTAL.

Through the kindness of the Bureau of Construction and Repair of the Navy Department the excellent facilities afforded by the wind-tunnel of the Washington Navy Yard became available for experiments on the frictional resistance of various surfaces. These experiments were made for the purpose of looking into the matter of surface friction with particular reference to surfaces of the sort which would be of most interest from the standpoint of aeronautics.

A glass plate about 9½ feet long and 34 inches wide was suspended vertically, with its surface tangent to the direction of the wind, by two wires fastened to the upper edge of the plate. The ends of the plate were enclosed in slots in faired struts, which were fixed rigid to the floor and ceiling of the tunnel, and stayed to prevent vibration. Smooth steel rollers attached to each side of the slots, at the upper and lower ends, prevented side movement of the plate. They did not ordinarily touch the latter, being set to allow a clearance of 0.01 inch. Thus the plate was free to move within limits only in the line of the air current.

The trailing edge of the plate was connected by a steel rod to the balance, allowing the horizontal force to be measured.

CORRECTIONS.

It was found by experiment that the ends of the plate, although protected by the struts, were affected by the air current. Tubes were set in the slots and connected with a hook gauge manometer. From the pressure at each end, the force on the plate was measured for different velocities, and by a faired curve, a set of corrections at different velocities was obtained. Both of these corrections are to be added since the air rushing past the slot in which the leading edge fits causes a diminution in pressure, and in the other slot, an increased pressure. Both of these changes in pressure would give a thrust against the wind.

The correction for the wires was found by adding 4 more supporting wires, making 6 in all and measuring the force on the plate with these additional supports, then removing the original wires and measuring the resistance of the plate at different velocities with four wires. Subtraction gave the effect of the two wires, which were used as supports in all regular tests. This correction is of course to be deducted from the observed force. To avoid masking, small wedges were used to hold the added wires away from the glass, the added wire passing around under the lower edge of the plate in each case.

SURFACES.

Plate glass was used as a standard, or ideal surface, since it is probably as smooth as any surface, and can be easily duplicated. The various fabrics were attached to this by a nitrocellulose varnish, by which, with a little practice, we were able to obtain a surface practically smooth, so far as unevennesses from wrinkles, etc., were concerned. The amount of varnish needed was so small and its colloidal nature such that it was possible to attach an uncoated linen to the glass without affecting the outer surface of the fabric appreciably. The linen surface could then be tested, and treated further as desired.

When more than two coats of varnish were applied, the surface was sand-papered between each coat.

Where fabrics were singed between tests, the singeing was done with a blow-torch.

The surfaces tested may be grouped as follows:

1. Plate glass.
2. Fabric surfaces with nap.
3. Fabric surfaces without nap (linen and cotton).
4. Varnished fabrics (cotton and linen).
5. Rubber coated linen (plain and aluminum surface).

The experiments were made at velocities of 30, 40, 50, 60, and 70 miles per hour. Owing to the large size of the plate (area about 50 square feet) the forces were large enough to enable considerable accuracy to be obtained. For example in the case of plate glass, the gross uncorrected force is about 0.27 pound at 30 miles per hour. On this account and also on account of the greater range of velocities we were able to detect variations in apparently smooth surfaces which were not noticeable in earlier experiments at low velocities.

The values of F (pound per square feet) the relative value of F compared with that for glass called for want of a better term, the resistance factor ($R.\ F.$) and the values of n and K are given in Table I.

TABLE I.—*Results of experiments on surface friction, in air, of various surfaces.*

[Tests were made in wind-tunnel, Washington, D. C.]

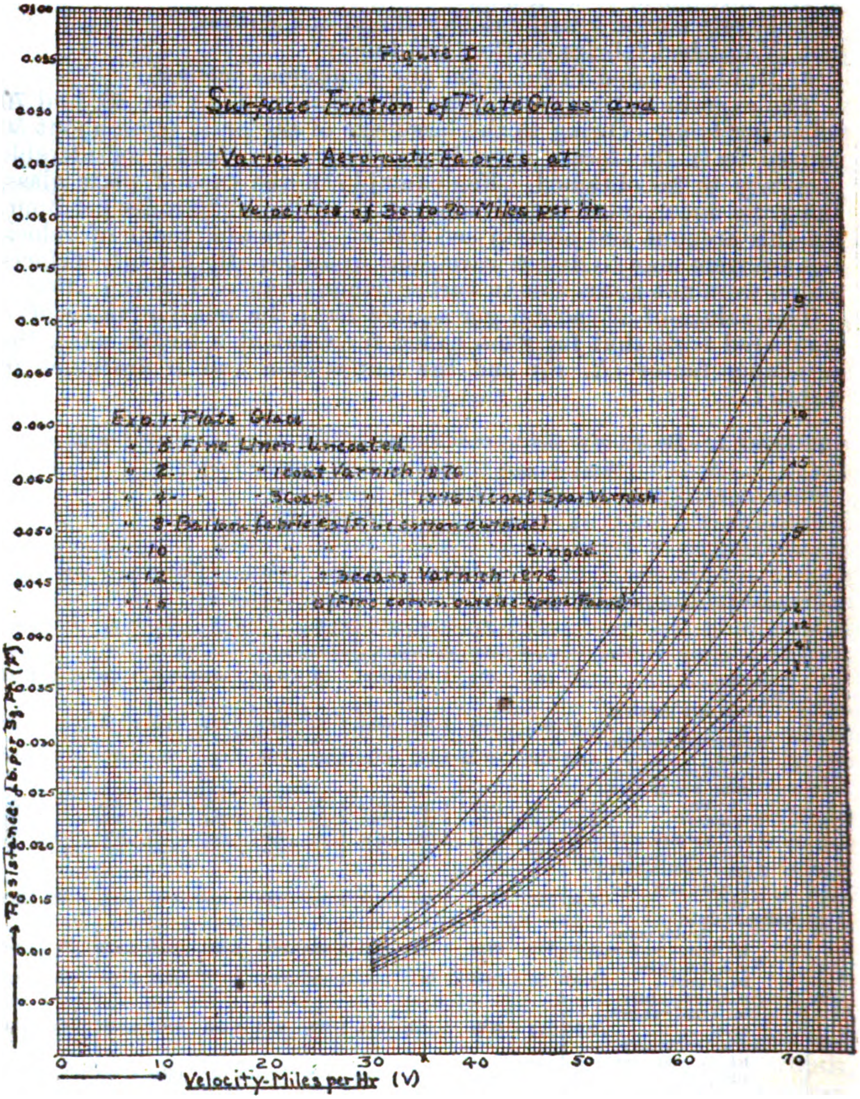
NOTE.—n, k, and F are values in equation $F = KV^n$. F = lb./sq. ft.
V = miles per hour.
$R.\ F.$ = Resistance factor = F observed/F glass.

No.	Nature of surface exposed.	n.	$K10^7$.	30 miles/hr.		40 miles/hr.		50 miles/hr.		60 miles/hr.		70 miles/hr.	
				F.	$R.\ F.$	F.	$R.\ F.$	F.	$R.\ F.$	F.	$R.\ F.$	F.	$R.\ F.$
1	Plate glass	1.81	166	.0079	1.000	0.0133	1.000	0.0199	1.000	0.0276	1.000	0.0364	1.000
2	Fine linen: 1 coat aero varnish, 1876	1.84	163	.0085	1.081	.0141	1.080	.0218	1.098	.0309	1.118	.0424	1.162
3	3 coats aero varnish, 1876	1.89	129	.00822	1.042	.0138	1.060	.0208	1.048	.0295	1.067	.0403	1.108
4	3 coats aero varnish, 1876, 1 coat spar varnish	1.84	153	.0081	1.081	.0135	1.034	.0204	1.028	.0287	1.038	.0387	1.061
5	Uncoated	1.94	128	.0095	1.205	.0161	1.234	.0249	1.254	.0361	1.305	.0496	1.362
6	1 coat varnish, 1877	1.85	149	.0082	1.034	.0136	1.040	.0206	1.039	.0292	1.056	.0395	1.085
7	3 coats varnish, 1877	1.85	149	.0082	1.044	.0137	1.040	.0204	1.028	.0288	1.041	.0394	1.081
8	3 coats varnish, 1877, 2 coats spar varnish	1.84	157	.0082	1.044	.0134	1.026	.0204	1.028	.0286	1.033	.0392	1.078
9	Balloon fabric: No. 3, double parallel, cotton surface	1.90	219	.0139	1.766	.0238	1.822	.0365	1.838	.0518	1.878	.0715	1.965
10	No. 3, double parallel, singed	2.05	96.5	.0103	1.311	.0184	1.408	.0292	1.470	.0426	1.539	.0603	1.654
11	No. 3, double parallel, 1 coat varnish, 1876	1.95	123	.0094	1.190	.0164	1.253	.0251	1.264	.0362	1.309	.0490	1.345
12	No. 3, double parallel, 3 coats varnish, 1876	1.85	153	.0083	1.056	.0139	1.063	.0213	1.072	.0300	1.082	.0403	1.107
13	No. 3, bias, cotton surface	1.95	207	.0133	1.691	.0227	1.739	.0343	1.728	.0494	1.782	.0694	1.902
15	No. 6, bias, special, cotton surface	2.03	99.7	.0099	1.252	.0180	1.378	.0281	1.414	.0412	1.490	.0556	1.528
16	No. 6 bias, special, cotton, singed	2.05	82.5	.0088	1.127	.0157	1.202	.0247	1.243	.0368	1.331	.0500	1.372
21	Aeroplane fabric: Rubber surface	1.83	165	.0084	1.070	.0142	1.082	.0215	1.083	.0299	1.081	.0393	1.079
22	Rubber aluminum surface	1.83	166	.0085	1.078	.0142	1.083	.0213	1.073	.0299	1.081	.0401	1 101

RESULTS.

QUALITATIVE.

The great resistance offered by fabrics with nap on the surface will be noted. The effect of the weave is shown by comparison of experi-



ments 9 and 15. Both fabrics are high-grade cotton, but probably that used in experiment 15 is closer woven and made of longer staple. Biasing seems to increase the index, but the effect would probably not be noted except at very high speeds.

Cotton shows a higher resistance than linen, although the cotton surfaces were finer weave than the linen. The linen yarn, while of more varying thickness, is smoother than cotton yarn, due to the nature of the ultimate fiber and its greater length. The linen yarn is more like a wire.

The effect of varnishing is very apparent, although no conclusion can be drawn as to the relative merits of various aeronautic varnishes. Probably it is more a matter of workmanship in applying and finishing the coat than any particular merit in the varnish itself. The use of a finishing coat of spar varnish gives some improvement.

The use of a varnish seems particularly advantageous in the case of cotton fabrics. This explains the good results obtained in Europe by varnishing the gas bags of dirigibles with cellulose acetate varnish, which both improves the gas-holding properties of the bag and decreases the frictional resistance. In a well-designed balloon most of the resistance offered by the air to the motion of the balloon is due to friction.

QUANTITATIVE.

If we plot the logarithms of the velocity (V) and frictional resistance in pounds per square foot (F) we obtain practically straight lines. From their slope we find the index n. Figure II shows the logarithmic plots for the most interesting cases. It will be noted that in many cases the value for 70 miles per hour seems to lie above the line, possibly indicating an increase in the index as velocity increases, due to greater turbulence. This has been predicted.

Using the slope obtained by logarithmic plots and F= pounds per square foot, V= miles per hour, we may obtain the constant K, as given in Table I.

From these results it will be noted that the smooth surfaces do not necessarily have lower indices. When this was first noted it seemed so anomalous that it was thought at first that there might be some experimental error. However, we note that Froude found a similar result (Table III) in the case of tin foil, varnish, and paraffin.

The high resistance of fabrics having nap on the surface is noteworthy.

Froude's results obtained with an 8-foot plane in a water channel were reduced to the same units, and to air conditions. The values are given in Table II. Considering the differences in conditions the agreement for smooth surfaces is close. The resistance of calico was somewhat higher than the cloth resistance found in our tests. from the photograph accompanying Froude's paper[1] the fabric used by him probably had about 80 threads per inch. Those used by us had about 120 threads per inch, and on this account presumably a smoother surface.

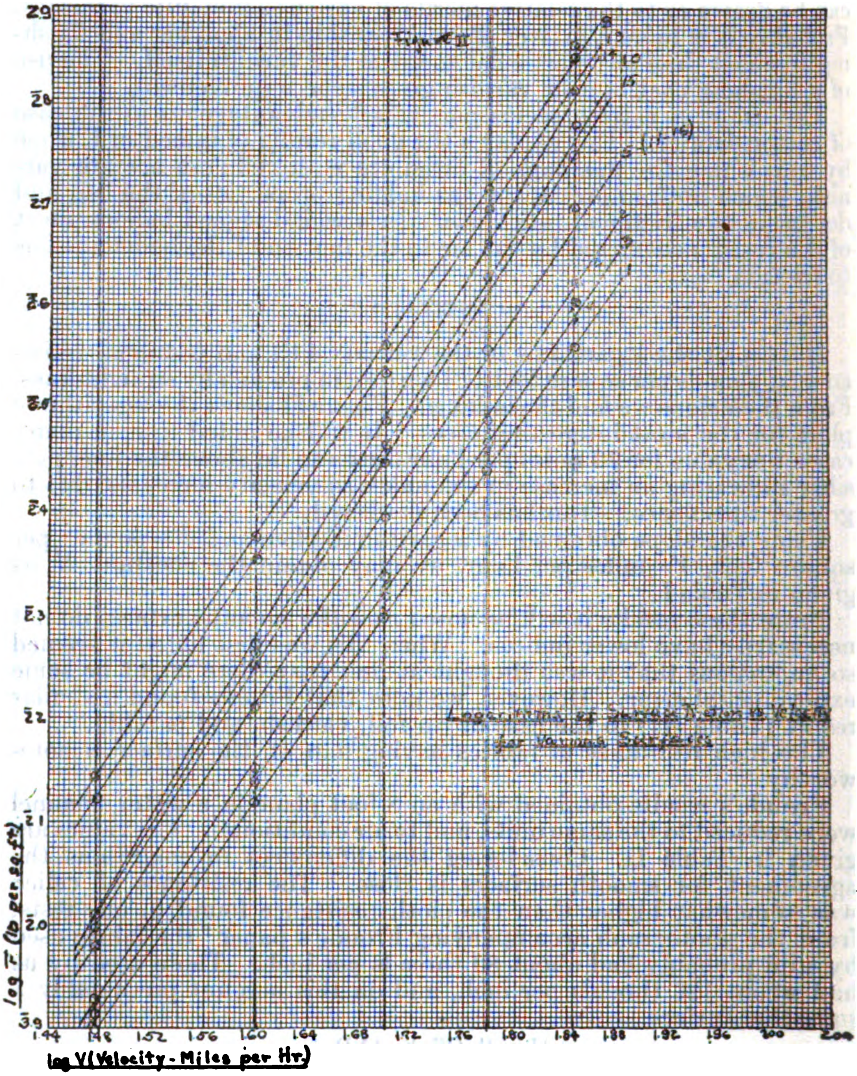
VALUES OF K AND N.

As already noted, smooth surfaces may show a higher index than rougher ones, while the coefficients K vary in the opposite direction. To obtain an idea as to the relative values of these two quantities, we plotted the values of K and N as shown in Figure III. It will be

[1] Brit. Assoc. Report, 1874, p. 249.

noted that the results of our experiments seem to show two distinct types of surface:

1. Those having nap on the surface have high indices and high exponents. They act somewhat similarly to calico and sand-coated surfaces investigated by Froude, and may be classed as rough,



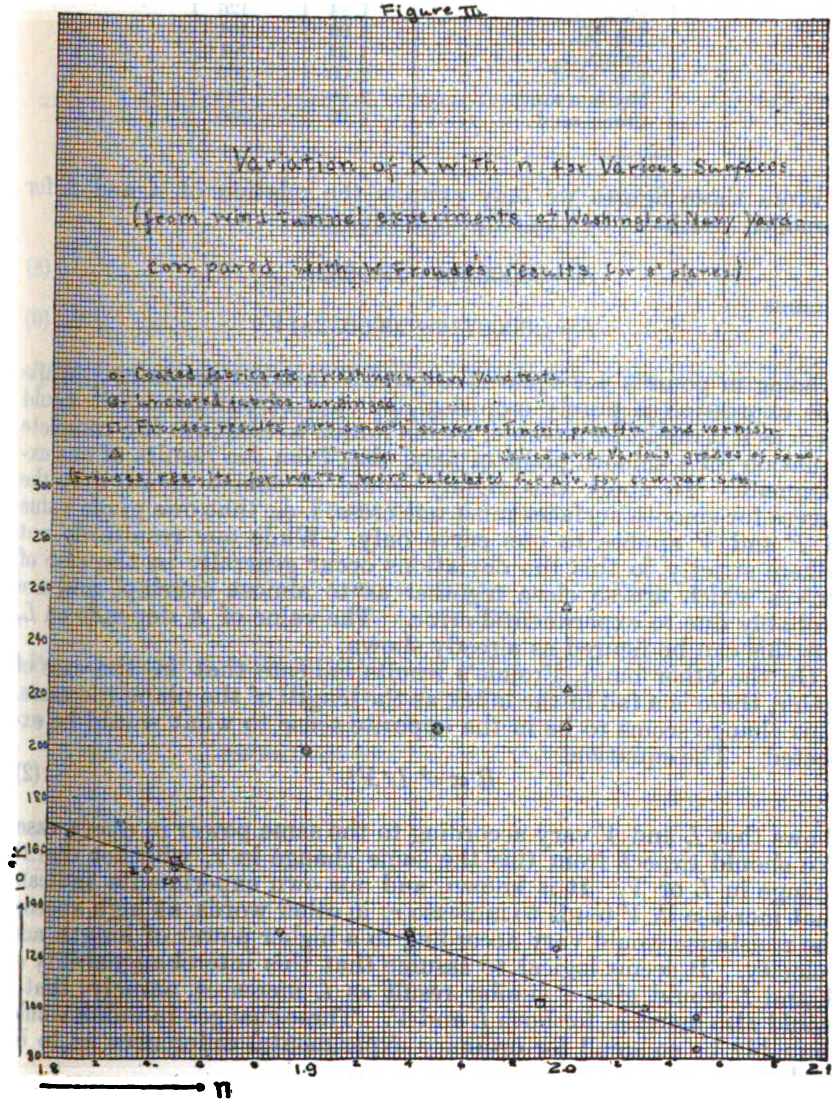
relatively. The index is 1.9 to 2, usually nearer 2, and the coefficient K, 0.00002 or more. (V in miles per hour.)

2. Surfaces which are free from nap, and more or less continuous and even. Fabric surfaces of fine threads closely woven and free from nap (due to singeing or natural great length of fiber, as linen)

are the roughest of this class. At the other extreme we have coated and varnished fabrics, which may approach glass in smoothness under good conditions.

Considering the nature of the quantities n and K, the points for smooth surfaces lie remarkably close to a straight line, the deviation

Figure III



amounting to not more than 6 to 8 per cent, except in two cases, and these fall on opposite sides of the line (Fig. III).

The values found by Froude for varnishes, tin foil and paraffin for an 8-foot plane in water are also shown (Table II), and fall close to the line. On the other hand, "rough" surfaces, calico and roughened sand, do not come near the line.

TABLE II.—*Results of Froude's experiments, calculated to air.*

[8-foot plane (600 feet per minute) K in terms of miles per hour.

Surface.	n.	$K.10^8$.
Varnish	1.85	156
Paraffin	1.94	126
Tin foil	1.99	101
Calico	1.92	261
Fine sand	2.00	209
Medium sand	2.00	223
Coarse sand	2.00	255

From these figures we may express the relation of n and K for "smooth" surfaces by the empirical equation—

$$K = .0000746 - .000032n \tag{8}$$

whence

$$F = (.0000746 - .000032n)\,V^n \tag{9}$$

F being in pounds per square foot and V in miles per hour. While this expression is purely empirical, in view of our results it would seem as if it might be possible, within limits, to evaluate the complete equation for a smooth plane of fixed size, from the results of one experiment. To apply this rigidly would of course mean that the curves for smooth surfaces must not cross, i. e., that one given value of F and V applies to one curve only. While our results do not adhere strictly to this the deviations occur generally in the case of curves which are so close together as to almost overlap, and are probably due to experimental error. The value of K depends on L, but this can be figured as already shown.

On the other hand, Froude's results indicate that in the case of water, there is a fall in the index as the length of the plane increases. This change seems to be in the opposite sense to what would be expected. The equation

$$R \propto v^s L^r V^r \tag{2}$$

shows that L and V vary according to the same power in every case. We should expect from this the same change in r, whether due to change in L or V. It is known, and our own experiments indicate that increase in V tends to increase r; in other words, at high speeds, the resistance would vary according to a higher power of length and velocity. It seems logical to assume that this interchangeability of V and L would give a similar result as L increases, namely, that r would also increase, for both L and V. These changes in index would probably be so small for ordinary experimental differences as to be negligible.

REPORT No. 7.

IN TWO PARTS.

THERMODYNAMIC EFFICIENCY OF PRESENT TYPES OF INTERNAL COMBUSTION ENGINES FOR AIRCRAFT.

BY COLUMBIA UNIVERSITY.

Part I.—REVIEW OF THE DEVELOPMENT OF ENGINES SUITABLE FOR AERONAUTIC SERVICE.

Part II.—AERO ENGINES ANALYZED WITH REFERENCE TO ELEMENTS OF PROCESS OR FUNCTION.

By CHARLES E. LUCKE,
Professor of Mechanical Engineering, Columbia University.

CONTENTS OF REPORT No. 7.

PREFACE.

In the preparation of this report, for which the time available was limited to a little less than three months, all the literature on aero engines that could be obtained in the libraries of New York City, or that could be secured by loan or purchase, has been consulted. Where valuable material was found in foreign languages, translations from the original have been made and in many cases whole papers or illustrations that seemed worthy of reproduction have been photographed for insertion. The report is divided into three parts, as indicated in the contents, and at the end of the second part the conclusions and recommendations will be found. The third part includes four appendixes consisting of reproductions of various valuable material referred to in the text, but separately presented so as not to break the continuity of thought and argument. In the very considerable labor involved in collection, translation, and digestion of the material, my colleague, Prof. F. O. Willhöfft, has rendered most valuable service, which is gratefully acknowledged.

CHARLES E. LUCKE.

NOTE.—The third part referred to herein contains so much matter that has appeared in published form and so much is in such form as to practically prohibit satisfactory reproduction of essential illustrative matter that the committee has determined to present only parts one and two. Part three is in possession of the committee and may be inspected.

H. C. RICHARDSON, U. S. N., *Secretary*.

REPORT No. 7.

PART 1.

REVIEW OF THE DEVELOPMENT OF ENGINES SUITABLE FOR AERONAUTIC SERVICE—ORIGIN, MEANS USED, AND RESULTS.

By CHARLES E. LUCKE.

Part 1 (a).—SERVICE REQUIREMENTS FOR AERONAUTIC ENGINES—POWER VERSUS WEIGHT, RELIABILITY, AND ADAPTABILITY FACTORS.

Transportation over land and water has been revolutionized by the addition of engine motive power to vehicles and boats to a degree that requires no study to appreciate but the contribution of the portable power plant to aerial navigation is even greater. It is fundamentally creative, for without the aeronautic engine air flight would be quite impossible. Not only does an engine constitute the essential element of the air craft, but the engine must be suitable for the purpose; it must have certain characteristics never before required or produced by engine designers. Success in flight and improvements in flying machines rests absolutely upon the success with which the engine and its accessories that make up the portable power plant can be made to fulfill the new requirements peculiar to the flying machine. Before someone flew, no one could specify just what the aeronautic motor should be able to do, except that, of course, it should be as light as possible and not stop in the air. Nor was there any demand for such an engine that would serve as an inducement to engineers familiar with engine production to build one. In short, while those few experimenters who were engaged in trials of balloons and gliding planes felt they might be helped if they could secure a proper light motor, no one felt sure it would be of service if produced, and of course no one could say how light it should be, or what other characteristics should be incorporated, except that of reliable continuous running during a flight. Formulation of some of these specifications may be said to date from about the years 1901–2, when the Wrights, on the one hand, and Langley, on the other, found that existing engines developed for other classes of service were unsuitable, the nearest approach being the automobile engine, then pretty uncertain in operation and weighing about 15 pounds per horsepower in the lightest forms—a weight that would not serve even if the operator were willing to risk his life on the possibility of engine stoppage in flight. It was apparent at once that redesign for reduced weight per horsepower was necessary, and the Wrights proceeded to rebuild the automobile engine, while Manly boldly departed from any existing

practice and built his five fixed radial cylinder engine, both Manly and Wrights retaining the water cooling of the most successful automobile engines. Both succeeded in reducing weight enough to make flight possible, the Wright engine producing a horsepower with about 7 pounds and the Manly with about 2.4 pounds of engine weight, the former with a 12-horsepower, and the latter with a 50-horsepower engine.

Thus was flight initiated with engine redesign for weight reduction, and so has flight improved in range, speed, and safety, with further redesign of engine in the 13 or 14 years that have elapsed since that time, but the end is not yet in sight. The progress that has been made in engine construction, principally in Europe, is truly amazing, in view of the unique character of the problem and the short time that has elapsed; but all this has only served to increase the demand of the aeronautic engineer on the engine designer and manufacturer, so clearly and firmly is the principle established, that progress in flying rests fundamentally on engine improvement. These years of experience, however, have resulted in some data, derived largely from laboratory tests on the characteristics of the engines that are most successful in flight, and in some more or less accepted formulations of the sort of service required of aero engines and their essential parts in addition to weight, speeds, power, and general reliability, that might be classified as adaptability factors.

Any engine, for whatever service, must be suitable, and its design must be based as much on the specifications for suitability involving these adaptability factors, as on the fundamental principles of thermodynamics, stress resistance and the properties of the materials available, and these adaptability factors must be derived from the users or operators of the machines before the engine designer can interpret them, preparatory to the incorporation into the engine proper of those structural elements that will make it suitable. At the present time there are available some conclusions along this line of experience, a few of which will be quoted and summarized before undertaking to analyze the engine structure proper.

After nine years' use of engine-driven aeroplanes the engine structure was summed up in 1912 by Capt. H. B. Wild, Paris, as from his own experience as follows:

The comparatively crude and unreliable motor that we have at our disposal at the present time is no doubt the cause of many of the fatalities and accidents befalling the aeroplane. If one will look over the accessories attached to the aero engine of to-day, it will be noted that it is stripped clean of everything possible which would add head resistance or weight. The designer of the aero engine is too anxious to eliminate what he deems unnecessary parts in order to reduce the weight of the engine, and in doing so he often takes away the parts which help to strengthen the durability and reliability of the motor.

Few engine designers seem to appreciate the importance of eliminating the least tendency toward variation of anglular velocity or in the torque, if the engine is required to drive a propeller. The effect of continually accelerating and retarding a propeller is most detrimental to its efficiency. * * * In front elevation an areo engine should be as compact as possible, so as to reduce head resistance.

Additional specific requirements named include—

(a) oil tank of six hours' capacity with reliable pump for forced feed lubrication, internal oil pipes, (b) standardized propeller hub and crank shaft end, (c) heater for carburetors and gravity feed of gasoline, (d) dual ignition and no loose wires, (e) exhaust silencer, (f) exhaust valve lifters for stopping and compression release for starting, (g) engine speed indicator, (h) cool valve seats. * * * Engine builders

generally would also do well to visit aviation grounds more frequently and to take more interest in the engines which have left their hands, * * * though in many cases the aviator does not leave the engine alone when it is working right, but tinkers with the different adjustments until they are all out of harmony with one another and places the blame where it does not belong. * * * The demand for a reliable motor is still prominent.

Writing in 1912, Awsbert Vorreiter, Berlin, gives the principal requirements which aviation engines have to meet, as—

First. Small weight referred to horsepower.

Second. Small consumption of fuel, water, and oil, so as to obtain the maximum possible radius of action with a given quantity.

Third. Absolute reliability since in the case of the dirigible engine hardly any—in the aeroplane engine absolutely no—repairs can be made during a flight.

In the demand for low weight per horsepower the requirement of the low fuel and oil consumption per horsepower-hour are included, since to-day it is no longer a question of getting a machine to fly for a short time only, but to construct flying machines for practical purposes, we have to figure on a running time of several hours. It may easily be shown by calculation that an engine very light compared with output, but requiring an excessive amount of fuel and oil, may weigh more per horsepower when the weight of fuel and oil are included than a heavy engine with low fuel and oil consumption. It is true that the oil consumption cuts less of a figure because the quantity of oil as compared with the fuel is small and in a good engine amounts to not more than one-tenth. As a most favorable value for fuel consumption of an aviation motor we may assume 0.536 pound per horsepower-hour, which value has been repeatedly reached in aeroplane engines. In dirigible engines figures as low as 0.514 pound have been obtained.

Hand in hand with the reliability goes the demand for durability and continuous maintenance of high capacity. It is here that older constructions of aviation engines sometimes fall down very badly. Only the continuous output which the engine is able to give is to be seriously considered in an aviation engine as distinct from the automobile engine. While the latter is only very seldom required to give its maximum output—and then only for a short time—the aviation engine almost always runs under full load.

Additional specific requirements mentioned include—

(a) carburetor action and engine performance must be independent of barometer, of temperature, of dust, and of tilting of engine, (b) uniform turning movement, (c) balance of engine parts, (d) high enough energy in rotating parts to produce fly-wheel effect to resist variable propeller resistances and maintain engine speed, (e) propellers give best efficiency at speeds lower than are feasible in engines—in some cases as low as half, (f) proper cooling of engine to insure lubrication, minimum distortion of metal parts, temporary or permanent, (g) locate exhaust discharge away from operator, (h) least weight of engine by designing for maximum feasible speed, maximum work per cubic foot of displacement, and least weight of metal of selected kind and cross section.

In a paper read before the institution of automobile engineers (London) in 1912, Mr. A. Graham Clark summarizes the qualities regarded as essential or desirable in an aeronautical engine, as follows:

(1) Reliability: Failure of the engine necessitates the immediate descent of the machine, if of the heavier-than-air type, which, should it occur at an inopportune moment, may be attended with disastrous consequences.

(2) High power weight ratio:

(3) Economy in fuel and oil:

Are desirable because of the increased radius of action.

(4) Low air resistance: The importance of air resistance becomes more marked with increase in the speed, as the power absorbed in this direction varies as the cube of the velocity. It may be remarked in this connection that the horsepower required to propel a flat plate 3 feet in diameter through the air is increased from about 6 to over 16 by increasing the relative velocity of the plate to the air from 50 to 70 miles per hour.

(5) Controllability or flexibility, although there is not the same need for it as with engines employed on automobiles, is none the less a desirable quality since at low

speeds of rotation the propulsive or tractive effort of the propeller is insufficient to move the machine along the ground, and hence the pilot will be able to start up without assistance should circumstances necessitate his so doing. Further, as the engine is not required to develop its full power in horizontal flight and when alighting, the ability to vary the speed during descent is certainly preferable to the crude method of switching the ignition off and on.

(6) Freedom from vibration: The necessity for elimination of vibration as far as possible will be obvious when the slender nature of the supports upon which the engine is carried is realized, especially as vibration of a dangerous character may be set up in the various parts of the machine.

(7) Accessibility: The question of convenience of access is frequently overlooked or, at any rate, disregarded on account of the care and attention which is now given to the class of engine before any extended flight is made. But it must be realized that from commercial considerations alone, apart from the addition to the time during which the machine can be used and which may, under some circumstances, be of value, it would be an advantage to be able to readily examine or dismantle any part, especially when the applications of the aeroplanes are more widely extended.

(8) Silence is desirable in any machine used for pleasure or sporting purposes, but when it is intended for employment on military reconnoissance duties it becomes of increasing importance to be able to maneuver without giving audible warning of approach, especially at night.

(9) Cleanliness is in the nature of a refinement, but it is none the less necessary since a dirty appearance is generally caused either by the oil splashed about during hand oiling or by the exhaust, both of which are objectionable—the former because the part requiring such attention is apt at times to run dry owing to the irregularity of the supply of lubricant, and the latter because it indicates an open exhaust.

Another contribution along similar lines worthy of reproduction is that of Granville E. Bradshaw before the Scottish Aeronautical Society (Glasgow), December, 1913:

There is probably no form of prime mover in existence that is more highly stressed or that has a more strenuous life than the aeroplane and there is undoubtedly no engine that has greater claims on reliability. The aeroplane, manufacturers' cry for the extremely light engine is probably greater to-day than it ever has been in the history of aviation. The demands of the authorities who purchase aeroplanes are such that probably as much as 90 per cent of the factors which determine the most successful machine are governed directly or indirectly by the weight efficiency and fuel efficiency of the engine. By the former is meant, of course, the number of pounds of weight for every horsepower developed. That the engine shall be extremely reliable is of course taken for granted.

Among the essential features of all successful aeroplanes are the following:

(1) It shall climb very quickly. This depends almost entirely on the weight efficiency of the engine. The rate of climb varies directly as the power developed and indirectly as the weight to be lifted. That the aeroplane shall be very efficient in this particular can easily be understood when one remembers that its capabilities of evading destruction from projectiles depend to a great extent on how quickly it can get out of range of such projectiles. It must also be efficient in climbing in order to successfully rise from a small field surrounded by tall trees which may be necessitated by a forced landing during a cross-country flight over a populous district.

(2) It shall have a good gliding angle; or, in other words, that from any given height it shall be able to glide for a great distance, is also governed indirectly by the weight of the machine, and consequently by the weight of the power plant, because a machine with a heavy power plant must be designed with a larger lifting surface and must be stronger in proportion. With the same lifting surface and head resistance the angle of descent of the heavy-engined machine will be steeper[1] than that of the light machine, as higher speed is necessary to support increased weight.

(3) It shall have a combination of fast and slow flying speeds. This is of paramount importance and one that aeroplane constructors are paying probably the greatest amount of attention to. The capabilities of a machine to fly slowly as well as fast depend almost entirely on the adoption of an extremely light and powerful engine. If the machine is designed for very high speed, a slow speed is only possible by the machine, and consequently the power plant, being very light. Note.—The wing characteristics of lift and drift are also very important.

(4) It shall be safe to handle in all winds both with and without the engine in operation. Aeroplanes have been built that will carry as much as 15 to 20 pounds

[1] The heavier machine glides faster, not steeper.

per square foot of supporting surface, but constructors nowadays agree that the lightly loaded machine is the safer to handle and the average loading on the planes is to-day generally in the neighborhood of 4 or 5 pounds per square foot. A heavily loaded machine depends to a great extent on high speed of flight in order to maintain it in the air. Should the speed fall, unconsciously to the pilot, through loss of engine power or from any other cause, the control becomes sluggish and will not answer quickly, the aeroplane, unless the nose is put down very quickly to increase the speed, flounders about like a log in the sea and generally ends in a side slip and one of these terrible nose dives that have deprived us of so many of our best pilots. The life of the pilot of the heavily-loaded machine is more dependent upon the good behavior of the engine than is the life of the pilot of the lightly-loaded machine, and the latter could probably go on flying in search of a good alighting ground with two or three cylinders not firing at all.

(5) It shall be able to remain in the air for long periods. This depends chiefly on the oil and gasoline consumption of the engine and without efficiency in this respect, the extremely light power plane is practically useless, as flights of only a few minutes duration are not likely to be of much use in serious warfare.

All the essentials just enumerated and particularly the last depend of course on the engine being absolutely free from any breakdown, which point has not been dealt with as it is not a debatable one. We are all without doubt of one mind on this matter.

Finally there are reproduced below some extracts from the Notice to Competitors issued by the British Government for 1914 competition for naval and military aeroplane engines, all bearing on the question engine-service requirements:

1. REQUIREMENTS TO BE FULFILLED.

(a) Horsepower, 90-200. (b) Number of cylinders to be more than 4. (c) Gross weight per horsepower, calculated for six hours' run not to exceed 11 pounds. The gross weight includes engine complete with carburetor devices connected up (exclusive of the gasoline tank and pipes), all ignition and oiling appliances, starting handle, all cooling appliances— e. g., fan guarding, air guides, and any water radiator and water connections and any oil left in the engine. It will also include all fuel and oil supplied for six hours' run and all oil containers and pipes therefrom.

The gross weight per horsepower is the total weight of the engine divided by the figure for horsepower, below which the output has not been allowed to fall throughout the six hours' run, with a tolerance of 3 per cent for small variations and inaccuracy of measurements.

(d) Shape of engine to be suitable for fitting in an aeroplane.

2. DESIRABLE ATTRIBUTES OF AN AEROPLANE ENGINE.

(a) Light total weight. (b) Economy of consumption. (c) Absence of vibration. (d) Smooth running whether in normal or inclined position and whether at full power or throttled down. (e) Slow running under light load. (f) Workmanship. (g) Silence. (h) Simplicity of construction. (i) Absence of deterioration after test. (j) Suitable shape to minimize head resistance. (k) Precautions against accidental stoppage—e. g., dual ignition. (l) Adaptable for starting otherwise than by propeller swinging. (m) Accessibility of parts. (n) Freedom from risk of fire. (o) Absence of smoke or ejections of oil or gasoline. (p) Convenience of fitting in aeroplane. (q) Relative invulnerability to small-arm projectiles. (r) Economy (in bulk, weight, and number) of minimum spare part equipment. (s) Excellence of material. (t) Reasonable price. (u) Satisfactory running under climate variations of temperature.

In the recently issued specifications issued by the United States Navy Department a number of items appear bearing on engine-service requirements which are abstracted and reproduced below for comparison.

"They shall be well balanced and produce no excessive vibration at any power. To be capable of being throttled down to 20 per cent of the revolutions per minute for full power. The weight of the engine complete, with ignition system, magnetos, carburetors, pumps, radiator, cooling water, and propeller not to exceed 5 pounds

per brake horsepower. Engine to be fitted with some type of compression release as a means of stopping it. To be fitted with a practical means of starting from pilot's seat when installed in an aeroplane. All moving parts not lubricated by a splash or forced lubrication system to be readily accessible for inspection, adjustment, and oiling. Ready means shall be provided for checking and making adjustment to the timing of the engine. To have an accurate and positive lubricating system which will insure a uniform consumption of lubricating oil proportional to the speed of the engine. All parts subject to corrosion to be protected from the effects of salt water. To be fitted with an approved attachment for obtaining the revolutions per minute. To be provided with means for preventing fire in case the engine is turned upside down. A hand-throttle lever and connections to carburetor to be provided that can be applied for convenient operation by the pilot. This lever to be designed with a positive means of retaining it at the throttle adjustment desired by the pilot. All bolts and screws without any exception to be provided with an approved positive means for preventing backing out due to vibration. No soft solder to be used in any part of the power plant."

Among the conditions for acceptance tests the following stipulation will be noted: "Motor to be run at full power for one-half hour under conditions approximating operations in the aeroplane in a heavy rainstorm."

At the present time many of the important conditions that an aeronautic engine must fulfill are pretty well settled, at least in kind, if not degree, but every day sees some new attribute announced as desirable, so that while it can hardly be said that aero service requirements for engines are now reducible to rigid specifications, they can be formulated with enough precision to enable an engine designer and manufacturer to undertake production with some prospects of success or acceptance. In so proceeding, however, no designer or manufacturer can afford to ignore past experience in engine construction nor, on the other hand, may old constructions be slavishly reproduced, for what was acceptable yesterday may not be to-day, and certainly will not be to-morrow.

All these service requirements can be classified under three headings for future more or less minute analysis.

POWER-WEIGHT RATIO, RELIABILITY, AND ADAPTABILITY.

If the engine complete with full tank is light enough it can be used—and is most useful when most light, and this weight involves many factors, each of which must be considered—some independent of others but many interrelated. The longer the contemplated flight, the more change there must be in the relation between specific fuel and oil consumption of the engine and the weight of the engine proper; so in any consideration of this item length of flight must be included. Not yet, however, has the engine or flight art reached the point where it is prepared to fix a minimum weight, though each year sees a definite maximum. In fact, one of the problems of the day for the aero engine designer is to discover means for lowering more and more both this maximum permissible weight that many can attain,

and the minimum possible attainable by only a few of the best—and with increasing flight lengths this is becoming more and more a matter of raising thermal efficiency, engine speed, and cylinder mean effective pressure, with corresponding reduction of lubricating oil. On the weight question, therefore, it is not the service conditions that specify what is wanted other than that it shall be as low as possible, but rather the engine designer is put on his mettle to say how far it is possible to go with due consideration to the other two elements—reliability and adaptability.

Reliability is demanded always, but how much? Some writers call for absolute reliability and others try to specify in numerical terms a value for one or another of its elements. For example, in the 1913 German tests, any engine that dropped to 85 per cent of its normal speed was rejected, and this stipulation was retained for the 1914 competition. Again, in the British conditions, the only power rating allowed was the least attained at any time in six hours. Now absolute reliability is impossible, for this would mean continuous, uninterrupted operation without variation in any respect, except at the operator's will. No such engine has ever been built nor will it ever be built. Obviously what is wanted is as great a reliability factor as the engine designer and builder can secure consistent with other factors, so here again, as with the unit weight factors, the problem is one for the producer to say how far the reliability can be assured, rather than for the user to specify and reject, especially on laboratory tests. However, rejection on such grounds is far more justifiable than acceptance, for the engine so accepted may fail on its first flight, due to some accident or to faulty operator's adjustment. What is needed here is, first, analysis of the reliability factor into its elements and by cooperation between engine designer and user, an agreement on reasonable values for each, so one will not promise, nor the other expect the impossible, but each understand clearly the limits—and more important, the reason for the limit—that means may be sought to eliminate the disturbing cause.

About the same situation is true with the third factor, adaptability, and its elements—such as shape, vibration, silence, accessibility, uniformity of torque. They may be specified to-day only in the qualitative or comparative way, though some of them are capable of formulation, quantitatively, such for example as torque variations. So far it has not seemed feasible to impose any such limits but to leave the field wide open to the designer with an expression of desire for as high a degree of success as is possible with each.

The reason for this state of affairs in the art is clearly due to its youth and the necessity at present, and for some time to come, for the maximum possible encouragement of invention, design, research, and manufacture, until it becomes clear to all just how far it is possible to go in any direction after engaging all available resources of talent, material, money, and plant. When, after such a period, one or more standard types of engine or engine parts—or even of air craft itself—have been established, then will it be feasible to specify more particularly and numerically all the elements of each of the factors of unit weight, reliability, and adaptability.

In the meantime, the problem is one of review of engines produced and an analysis of their construction and performance as a whole and with it a similar analysis of fundamental possibilities. This must

include a more or less standard examination of each of the essential parts of the engines and the relation of form and arrangement to the perfection or imperfection with which the part performs its partial duty or function. Even now, as Soreau, reporting the French tests, points out, the relative importance of low engine weight proper, reliability and life, and consumption of fuel and oil, originally considered in this order, has been reversed, experience indicating that the last is now first and the first last.

Part 1 (b).—MEANS EMPLOYED UP TO THE PRESENT TO PROMOTE AERO-ENGINE DEVELOPMENT, INCLUDING POSSIBLE MEANS NOT EMPLOYED.

Any new art develops as fast as encouragement is offered or as fast as the necessary means are made available and intelligently used, and, of course, inversely as the difficulties involved. It would be hard to find any class of machine among those developed in modern times that had to face the same inherent difficulties incident to the nature of the problem, or one that received, at least for the first few years, so little real encouragement and assistance as this one, the aero engine. The initial step is one of conception, which must be subsequently checked by construction and trial. This must be followed by commercial perfection, which requires endless research by test and computation—not only on the machines as a whole but to a larger degree on each element of the problem that analysis indicates to have separate entity, and on groups of elements that have coordinate functioning. Construction is here again necessary, not only of the complete machine, but also of variants on each part, and of instruments, appliances, models, and apparatus that do not themselves enter into the result but are essential to its attainment. Finally, with commercial perfection, further construction work is necessary to create the means of rapid large scale reproduction within the limits of dimensions needed for interchangeability of parts, i. e., establishment of the manufacturing plant. It must be understood, however, that these three steps that must be undertaken in this order on general principles may not be repeated many times over even when concerned with the same product, such as the aero engine, or that the earlier step ceases when the latter is inaugurated, for this is not true. These three stages or periods of development may, for the want of better terms, be designated as, first, the period of invention; second, the period of design; and, third, the period of manufacture. Design can not be undertaken before invention, whether that invention be of the patentable sort or not. Yet invention undoubtedly proceeds long after design has been firmly established and, of course, while manufacturing may not be undertaken until both invention and design have accomplished a reasonably commercial perfect product, it goes without saying that both invention and design will continue during the whole of the manufacturing period.

With the exception of invention, which needs little encouragement beyond a stimulation of the imagination, the primary factor in successful development is money, for, with sufficient funds, the necessary professional skill, labor, materials, and plant may be secured for carrying out the steps of design and manufacture. Of course, money may be, and usually is, misspent in these developments, especially when the control is in the hands of persons lacking engineering skill and

experience, so there should be added the requirement that organization be associated with money.

No better illustration of this situation can be given than that of the steam turbine, whose period of development practically coincides with that of the aero engine, but which has been brought to a state of commercial perfection that the aero engine has not even approached, partly by reason of the better understanding of the service requirements that are not yet fully formulated for the flying machine, but almost entirely because of the differences in the means employed for the development. The steam turbine had its invention stage, and while invention still proceeds it is largely superseded by rational design for manufacture, under skillful guidance, under proper organization, suitably financed and satisfying an ample, well-understood market demand. The aero engine is still largely undeveloped, invention is still more active than design, and the almost microscopic, painstaking research required to establish the data necessary for design is almost wholly lacking, so naturally manufacturing in the true sense of the term is correspondingly nonexistant, though a few individual models of engines are being reproduced in fair numbers.

The millions of dollars needed for rational perfection for manufacture become available to the suitable organization ordinarily only when a permanent market is clearly in sight and when the service requirements of the product are reasonably definite. In the case of the aero engine, this market has been absent or at least very uncertain and the service requirements very hazy—both so much so that under ordinary conditions the aero engine could not have reached even the degree of perfection so far attained, unsatisfactory as it may be, without other incentives or different sorts of encouragement than the ordinary article of commerce receives as, for example, again the steam turbine. This special element in perfecting the aero engine is that of governmental aid based on military necessity, a comparatively recent force in the situation but now a very strong one in Europe, but almost wholly lacking in America. The military establishment can purchase what it needs in the market only when there is a reasonably strong civilian demand for the same article, strong enough to warrant the financial investment necessary for its perfection—and such is the case with the automobile and traction engine. On the other hand, when there is no such demand, however active invention may be, rational design and manufacture will be absent and must be supplied by the Army and Navy through their own organization and plants, or, as an alternative, reasonably steady annual governmental appropriations for purchasing sufficient quantities by the military departments may be made the basis of support for civilian production. Such is the case, for example, with ordnance and to some extent with ships.

For several years after the demonstration that engine-driven air craft could make successful flights the only encouragement offered to development was that of adventurous sport. Men whose incomes were sufficient became purchasers of machines for their own amusement and others bought machines for making exhibition flights before paying audiences for the profit to be derived. Both sorts of operators took chances with the imperfections of the machine in a spirit of adventure or speculation, but practically all made short flights that made no such demand on the engines as is now standard. Men such as Eiffel, and Deutsch de la Meurthe, should be mentioned for their con-

tributions of large sums of money for scientific investigations, not of engines, however, and the national subscription funds of France and Germany, all of which assisted in development. In many cases, even with these short flights, the engine was taken apart, cleaned, repaired, and readjusted before each ascent. Even as late as September, 1912, Mr. Earle L. Ovington, writing in the Scientific American reports:

> Usually every 15 hours of running, and at most every 20, my mechanics (skilled men) went through the interesting process of separating every single component part of my motor, one from the other. The valves were reground and retimed, because of valve-gear wear, new valve springs were inserted, the tappet rods were adjusted, and the whole motor was given a rigid inspection. The Gnome, in common with most rotary motors, uses castor oil as a lubricant, hence at each cleaning great quantities of carbon were removed. I claim that any engine requiring such attention may rightly be termed "delicate." How far would you get in an automobile if you had to take the entire engine to pieces and readjust practically every working part of the whole motor every 15 or 20 hours of service?

In an article in the Auto Car of March 28, 1914, we find the following statement:

> The Gnome engine requires cleaning out after about 24 hours' continous running if it is to be kept in tune. The French military regulations demand that the Renault be cleaned out after 200 hours' running. Users of other aeroplane engines have told the writer that cleaning carbon out is hardly ever necessary.

With such an uncertain and capricious market perfection of the aero engine could hardly be expected in a whole lifetime, especially as the amount of business in any one country would scarcely suffice to support one producing establishment, and that one unable to bear the expense of the high-salaried engineers competent to supervise the work and when, at the same time, the stimulus to the imagination created by the idea of the mechanical flight produced thousands of inventions and inventors, each seeking and many finding financial support, under the influence of the excitement of the time rather than from any sound business basis. Failures necessarily must be numerous under such conditions, and every failure, whether of mechanism or finances, set back the art and discouraged the rest.

During this period the military organizations of all the nations watched results and purchased a few machines for experimental purposes, out of which grew the conviction now so firmly established and so thoroughly demonstrated in the present European war that, however imperfect the aeroplane, it is a military necessity and must be perfected. Perfection being impossible or too slow without governmental aid, plans were formulated by the European nations, one after the other, and, in addition to creating a corps of flying men with suitable cooperation with the military establishment, competitive tests for aero engines were organized by Germany 1912–14; France 1909, 1911, and 1913 in cooperation with the Ligue Nationale Aérienne and the Automobile Club de France; Italy 1913; and England 1914, in which substantial money prizes were offered for successful machines and in some cases buying orders given to winners in the contest. It was the intention to make each of these contests an annual event so as to not only continue the development of engines under this incentive, but to show clearly the annual progress by comparison of the entries in successive years on the basis of their performance, in relation to their form, materials, and proportions. The contests so far held are summarized in Appendix 1, which also reproduces the conditions and such of best results with

some discussions and interpretations as are obtainable from published reports. Unfortunately the European war has interrupted reports of such tests as were completed in 1914 and prevented the carrying out of others, so that the latest information of this class is not now obtainable.

Besides these governmental contests with cash prizes and purchasing orders, which are undoubtedly the biggest single influence so far brought to bear on the rational development of the aero engine, there are some other coordinate factors to be noted, and these are civilian contests conducted by organizations interested professionally in promoting the art or by individuals, reports of which are also given in Appendix 1, with the Government contest reports. Among these private contests are to be noted in France Competition of La Ligue Nationale Aérienne, 1911; Automobile Club of France, 1913; England, Alexander contest, first for British-built engines, 1909, and second for any engine, 1912.

Finally, there must be noted among these influences for good in the rational development of the aero engine the establishment of laboratories for testing engines alone or flying-machine supporting and control elements alone, or both engine and air craft, and reference is made to the paper by Dr. A. F. Zahm, May, 1915, reproduced in Appendix 2, with other laboratory references in addition to those contained in the contest reports of Appendix 1. Some of the results obtained in these laboratories are not published and apparently but little work has been done on engines. It is assumed that most of the laboratory work on engines so far done is such as to be of value only to individuals seeking to perfect their own engine, or, believing it perfected, seeking an independent test report to enlist capital for manufacture or to serve as an advertising inducement to purchasers.

As a consequence, the conclusion must be that the largest single factor in the recent rapid development of the aero engine is governmental, involving the establishment of official organizations to study the problems, the operation of laboratories to determine by test the results attained by designers and producers, especially when large and regular purchasing orders are involved to support civilian development and manufacturing establishments, or in the absence of sufficient orders, and perhaps in addition to them, the distribution of sufficient cash prizes, whether originating in governmental appropriations or private and institutional donations.

Great as has been their influence for good in aero engine development, these contests have not yet been under way long enough to have accomplished more than a small fraction of what may be so attained, nor can this contest means be regarded as either sufficient or without faults. There is an inherent danger that the results of such tests be misinterpreted, and in fact there is even a bare possibility that they may exert a retarding influence on the art. Naturally competitors design engines and enter them to win a prize and the conditions of the contest become the controlling factor in the preparation of an engine for entry. If these conditions place undue weight on factors that are not of primary importance to the engine as it works in place in actual flight, it is easily possible that not only may the best engine from the actual service standpoint be rejected but, worse than that, the bulk of these workers who are engaged in development will be led away from lines that are truly legitimate in order that by following the lines prescribed by the rules

they may secure the necessary cash to continue. In view of this possibility too much care can not be exercised in the preparation and regular revision of these contest rules and conditions in order that the result may be what is wanted and what is needed by the whole art, instead of a perfect attainment of a merely hypothetical standard.

Attention is called to these rules in the appendix and especially to the alterations in later German rules as compared with the earlier, all directed toward greater latitude and greater reliance on the judgment of competent engineers and proportionately less on the numerical values of those quantities that are subject to measurement and which require experienced cultivated judgment to interpret into terms of engine goodness which often depends as much on intangible things such as workmanship, ruggedness, simplicity, and the other factors of general adaptability. In this connection there is a most significant, though guarded, statement at the end of the second report of the Deutsche Versuchsanstalt für Luftfahrt by Dr. F. Bendeman, January, 1913, the best document on the subject in existence herewith quoted:

> The further development of the aeroplane and engine construction makes it seem desirable that in a future competition the engine be judged more in its relation to the *operating conditions* of the machine.

Even at best, better than yet arranged, the contest exerts but an indirect effect on engine development, it results in a public statement of a judgment of the machines relatively considered with reference to the rules and to each other. The winner is stated to be that engine that has best fulfilled the prescribed conditions; it is announced as better than others in this respect and that is all. Any test that measures only over-all results, whether of fuel and oil consumption, weight, horsepower, speed, unbalanced forces, torque variation, or similarly measurable quantities is faulty as a factor in direct development of engines to perfection. The only sort of direct contribution that can lead to true scientifically sound advance is that generally termed research which involves the patient analysis of not only over-all performance but more particularly of the performance of each part intended for the execution of every separate function, the accumulation and interpretation of data for the diagnosis not of the faults found but the determination of their causes and discovery of remedies, all of which are to be followed by the application of the promising prospective cures with test checks on their success. This sort of work requires the highest class of training and skill and is to be carried out as much in the computing and drafting room as in the laboratory, but to do most good to a young art struggling blindfolded to advance, every result must be not only convincingly and accurately arrived at but must be given wide publicity. This is the kind of development work that must be done and has not yet been attempted anywhere outside of a few establishments producing engines and in them is only carried on to a small degree because of the heavy expense, and naturally this same expense is sufficient reason for nonpublicity.

Research and publicity of the data of research are far more needed than public contests and their reports. While the latter are in a way an expression of the conclusions of the former, they give no clue to the means found necessary to bring them about no more than the sight of a man cured of an illness by a physician gives the observer any idea of the physician's diagnosis and methods of cure.

The advance of the profession or art is more important than an isolated case of perfection.

However sadly lacking are the data of research on aero engines, what literature there is descriptive of engines, of conditions of flight, of experiences, successes, and failures, of contests and over-all performances should be most thoroughly collected and recirculated in the form of collected papers.[1]

Part 1 (c).—GENERAL CHARACTERISTICS OF PRESENT AERO ENGINES: POWER, SPEED—ENGINE, RADIATOR, WATER, GASOLINE AND OIL TANK, WEIGHTS—FUEL AND OIL CONSUMPTION, AGGREGATE POWER-PLANT WEIGHTS WITH FULL TANKS FOR GIVEN LENGTH OF RUN—ENGINE TYPES.

Since the period 1901–1903, with the two engines, Wright of 12 horsepower, a converted four-cylinder, vertical automobile engine weighing for engine alone about 7 pounds per horsepower and the then novel Manly design of radial star fixed cylinder engine of 50 horsepower, weighing for engine alone 2.4 pounds per horsepower, there has been produced in the interval more than a hundred different designs that have survived the stage of first trial. There are now on the market perhaps half this number of different engines being regularly reproduced, each to some extent and several quite extensively (for this art), and of several of these designs engines are available in more than one size.

While most of these engines have capacities of 50 horsepower, more or less, the number that reach or exceed 100 horsepower is steadily increasing, following the demand of the aeroplane and made possible by greater experience in construction of the smaller sizes. It is worthy of note that the 1913 winner of the Gordon-Bennet cup race carried 200 horsepower and the Russian Sikorsky used in his 17-passenger machine 400 horsepower in two engines. The latest Curtiss aeroplanes carry 320 horsepower in two engines, and the English Sunbeam catalogues a single engine of 225 horsepower. While some types of engine construction give trouble in large sizes, there is no reason to believe that the limit of engine capacity has been anywhere nearly reached, for even if a high limit of cylinder diameter be found, which is not the case yet, multiplicity of cylinders can carry up total capacity. Naturally there is no limit to the number of separate smaller capacity engines that may be placed in one air craft except that as the weight per total horsepower of two or more engines is always greater than of one engine of equal aggregate capacity. On the question of total power there is no high limit in sight, though the normal is somewhat about 100 horsepower. Germany in 1914 required for her latest army planes 80 to 120 horsepower and more for hydroaeroplanes, while the United States Navy specifications of 1915 call for 100 to 160 horsepower. It may easily happen that this trend toward larger engine capacities will result in the elimination of some styles of engines which only operate well in smaller units, or what is more likely as the number of different types of air craft increases in the limitation of engine type to flying machine type.

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[1] A more or less complete bibliography of aero engines is offered in Appendix 3 as a nucleus, as full as the limited time available will permit, and to show the character of some of these papers, a selected few are reproduced. To complete this bibliography and republish these papers will be of very great service to the art, especially if there be added a corresponding collection of patents in all countries either in full or in abstract.

Speeds of engines are all in excess of 1,000 revolutions per minute, most engines operating normally between 1,200 and 1,500 revolutions per minute, with a few exceeding 2,000 revolutions per minute, the highest being the Sunbeam engine, rated at 2,500 revolutions per minute. These, of course, are the speeds when carrying normal full load and therefore a reduction of load, such as would follow a change of propeller to one of lesser torque or such as results from a gust of air in the direction of propeller air discharge, will accelerate the speed. This is because the full throttle, mean torque, of these engines is about constant up to speeds considerably in excess of their normal, probably approaching 2,000 revolutions per minute for most of them, though in all mean torque will decrease beyond some critical speed, due to valve and port resistance on the one hand and insufficient speed of combustion on the other. Below this critical speed, which is partly a matter of design of valves and ports, the horsepower is directly proportional to speed, and so speed increase is a natural means of reaching the light weight per horsepower of engine. It does not necessarily follow, however, that, because in a given engine the high speed does not reduce the mean driving torque, the engine will not suffer from the speed. In fact, it is just here that so many of the failures are found, the engines literally shaking themselves apart and pounding or grinding themselves to pieces. With due attention to the forces developed by high speed, and to bearing friction effects of rapid motion over loaded sliding surfaces, and to the suitable arrangement as well as proportions and materials for it, there is no reason why, from the engine operation standpoint, the present normal range of 1,200 to 1,500 revolutions per minute should not be exceeded if the service demands it, though the engine designer's problems are easier, the lower the speed. It must be noted that there seems to be no essential relation between propeller speed and engine speed if the operator has no objection to gearing, which in these days of automobile alloy steel gears can be made probably the most reliable element of the machine. Testing of engines at excess speeds to limits of unbalanced forces, bearing friction wear, and mean torque would seem to be a rational means of assuring that the operating speed itself will not cause trouble however much other causes might enter. Such a practice would be somewhat in accord with the hydrostatic test of 50 per cent excess of working pressure now standard with steam boilers and somewhat similar because each may in emergency reach that excess, in the one case of speed and in the other of pressure which may cause failure.

Engine weights now attained, per horsepower developed, exclusive of tanks, radiators, and supplies of gasoline, oil, or water, by the several classes or types of machines, at their own normal speeds, have not been materially lowered for some time, attention having been rather concentrated on the reliability and adaptability factors with existing weights, instead of on further weight reduction, though this will undoubtedly come in time. There is, however, a rather marked division of unit engine weights according to system of cooling of engine, whether by air or by water, involving besides water weight, that of radiator. For example, the most popular French rotating star cylinder air-cooled Gnome engine weighs just about 3 pounds per horsepower, ranging from 2¼ for 100 horsepower to 3½ for 50 horsepower, while the vertical water-cooled automobile style and winner of the last German competition weighs 4.2 pounds per horse-

power. (A number of tables and some charts of engine weights are given in the papers in the appendix which are not repeated here, as it would serve no good purpose.) Attention is however called to the fact that the highest weight reported in the German competition (second) is about 6 pounds. This is about the present high limit, while 2.2, the value for the Gnome 100 horsepower, is the low limit, the water-cooled group occupying the upper portion of this range, the air-cooled, its lower portion. It is most interesting to note that the middle range in the neighborhood of 4 pounds is occupied by both types, providing that water-cooled engines can be built as light as some kinds of air-cooled engines, or that air cooling does not necessarily result in the lightest engine.

Whatever influence in this unit weight of engine alone the general arrangement may have is shown by a comparison of figures for some typical differences of arrangement or type. It ordinarily is of the order of a fraction of a pound and may be entirely offset by some other structural feature, not a factor in general arrangement, such as the use of a steel cylinder in one arrangement against a cast-iron cylinder in the other, or a high mean effective pressure in one against a low value in the other due to different weights of active mixture taken in per stroke. It would seem that cylinders set radially about a short single throw crank should yield an engine weight per horsepower less than the same number of cylinders set in line along a long multi crank shaft. Also that a V arrangement of two lines of cylinders should weigh less than a single line because of shaft and frame differences, but it is not clear whether a given output in four cylinders will yield a greater or less weight than in six or eight similarly arranged, nor is it clear just what difference in horsepower, if any, should be expected per unit of displacement per minute in water-cooled as compared with air-cooled cylinders. As pointed out, according to the general figures given, the aggregate of all such differences lie between the limiting weights of about 2½ pounds and 6 pounds per horsepower and therefore cover a range of about 3½ pounds per horsepower for such engines as are now in use and for which test data are available. Just how much of this difference is chargeable to one or another of the factors of arrangement, detail form, proportions, or material, it is not possible at the present time to accurately fix, but as a first attempt the following figures, Table I, are given as derived from available data:

TABLE I.—*Weights of engines in pounds per horsepower versus type construction.*

Cylinders and cooling.	Class construction.	Engine name.	Authority.	Weight.	
				Alone.	Plant.
				Lbs.	*Lbs.*
Water-cooled fixed cylinder	4 cylinders in line.	Bens	Bendemann	3.57	4.20
	6 cylinders in line.	Daimler	do	3.75	4.36
	8 cylinders in line.	Sturtevant	Maker	3.9	
	12 cylinders U	Sunbeam	do	4.0	
	Radial star	2-cycle laviator	"Flight"	3.02	
Air cooled:					
Fixed cylinder	8 cylinders U	De Dion Bouton	do		5.81
	12 cylinders U	Renault	do		6.35
	Radial star	British Anzani	Maker		4.0 3.4 4.1
	Special	Ashmussen	do	3.3	
Rotating cylinder	1 radial star	B. M. and F. W	Bendemann	4.72	4.72
	2 radial star	German Gnome	Maker		3.086 2.480 2.701

TABLE I.—*Weights of engines in pounds per horsepower versus type construction*—Contd.

Cylinders and cooling.	Class construction.	Engine name.	Authority.	Weight. Alone.	Weight. Plant.
				Lbs.	*Lbs.*
Water-cooled fixed cylinder	4 cylinders in line.	Daimler	Bendemann	4.29	4.92
	6 cylinders in line.	do	do	4.60	5.23
	8 cylinders in line.	Curtiss	Maker	4.0 3.4 4.4	
	12 cylinders U	Rausenberger	do	3.9	
	Radial star	Salmson	Soreau		5.47
Air cooled:					
Fixed cylinder	8 cylinders U	Renault	"Flight"		5.66
	Radial star	British Anzani	Maker		3.6 3.7 3.4
Rotating cylinder	1 radial star	Gyro	Bendemann	4.81	4.81
	2 radial star	Le Rhone	Maker		2.9
Water-cooled fixed cylinder	4 cylinders in line.	Daimler	Bendemann	4.74	5.37
	6 cylinders in line.	Argus	do	4.60	5.23
	8 cylinders in line.	Sunbeam	Maker	4.1	
	Radial star	Salmson	"Flight"	4.15 3.42 3.3	
Air cooled:					
Fixed cylinder	8 cylinders U	Wolseley	"Eng'y".		[1] 4.7
	Radial star	Edelweiss	"Flight"		3.68 2.82
Rotating cylinder	1 radial star	Gnome	Bendermann Lumet.	3.26	3.26
Water-cooled fixed cylinder	4 cylinders in line.	Daimler	Bendemann	4.89	5.52
	6 cylinders in line.	Mulag	do	5.14	5.77
	8 cylinders in line.	Clerget	"Flight"	3.2	
Air cooled:					
Fixed cylinder	Radial star	2-Cycle Laviator	do		3.05
Rotating cylinder	1 radial star	Gnome	Bendemann Lumet.	2.93	2.93
Water-cooled fixed cylinder	4 cylinders in line.	Daimler	Bendemann	5.09	5.72
	6 cylinders in line.	Schröter	do	4.65	5.28
	8 cylinders in line.	Laviator	"Flight"	3.43 3.48	
Air-cooled:					
Rotating cylinder	1 radial star	German Gnome	Maker		3.439 3.197 2.590
Water-cooled fixed cylinder	4 cylinders in line.	N. A. G.	Bendemann	4.33	4.96
	6 cylinders in line.	Hall Scott	Maker	4.32	5.15
	8 cylinders in line.	Panhard Levassor.	"Flight"	4.4	
Air-cooled rotating cylinder.	1 radial star	German gnome	Maker		2.978
Water-cooled fixed cylinder	4 cylinders in line.	N. A. G.	Bendemann	4.36	4.99
	6 cylinders in line.	Austro-Daimler	Maker		4.5
	8 cylinders in line.	Wolseley	"Eng'y"	5.38	
Air-cooled rotating cylinder.	1 radial star	Le Rhone	Maker		3.1
Water-cooled fixed cylinder	4 cylinders in line.	Argus	Bendemann	3.77	4.40
	6 cylinders in line.	Benz	Maker	4.1	
	8 cylinders in line.	E. N. V.	Alexander Prize Report.		6.1
Air-cooled rotating cylinder.	1 radial star	Gyro	Maker		3.25–2.88
Water-cooled fixed cylinder	4 cylinders in line.	Argus	Bendemann	4.38	5.01
	6 cylinders in line.	Wright	Maker	5.1	
Air-cooled rotating cylinder.	1 radial star	Clerget	"Flight"		3.3–2.7

[1] Without flywheel.

TABLE I.—*Weight of engines in pounds per horsepower versus type construction*—Contd.

Cylinders and cooling.	Class construction.	Engine name.	Authority.	Weight.	
				Alone.	Plant.
				Lbs.	*Lbs.*
Water-cooled fixed cylinder	4 cylinders in line.	Sturtevant	Maker	4.0	
	6 cylinders in line.	Green	MacCoult	4.4	
Water-cooled fixed cylinder	4 cylinders in line.	Cheno	"Flight"	3.91	
				2.87	
				3.97	
				2.8	
Water-cooled fixed cylinder	4 cylinders in line.	Clerget	"Flight"	4.28	
				3.96	
Water-cooled fixed cylinder	4 cylinders in line.	Green	Alexander Prize Report.	5.48	6.8

These figures show a consistent weight excess for cylinders in line over radial, but no conclusions can be drawn on the relations between water *vs.* air cooling for either fixed or rotating cylinders. More data and data in greater detail than are now available are necessary before such conclusions are possible. In later tables the figures are analyzed with reference to other units and some desirable conclusions are derived, but always there must be noted the data which one would expect at this date to be quite full and reliable are found to be both meager and uncertain.

To the weight of the engine proper with all the parts that are permanent features built on or into it, such as the magnetos, oil pumps, air fans, and water-circulating pumps, there must be added the weights of other parts to get the weight of the power plant with empty tanks. These additional parts may be called the engine accessories. All such supplies, as fuel, lubricating oil, and water needed for a given length of run, will add more weight, the amount of which depends partly on rate of consumption, partly on the general arrangement, but principally on the length of the run. The fuel weight to be carried per horsepower varies directly with the length of run and inversely as the thermal efficiency of the engine. The oil weight, while varying somewhat with the length of run, probably is not directly in proportion to it and certainly has nothing to do with the thermal efficiency of the engine, but rather depends on such factors as quality of the oil, mode of its application, style of engine, bearing temperature and surface pressure and speed. Water in any properly proportioned jacket and radiator system should not be lost, and its weight may therefore be regarded as a fixed quantity entirely independent of the length of run and additive as is a piece of accessory equipment such as the radiator itself, though its weight value is, of course, a function of the aggregate internal volume of jackets, piping, pump and radiator.

It needs only a superficial examination of these weights of accessories and supplies compared to engine weights to see that for short runs, engine and accessory weights are more important than supply weights, but that for long runs the supply weights, especially those of fuel and lubricating oil, will become the controlling factors in

plant weight, and the longer the run, the greater the difference, and the more dependent does plant weight become on thermal efficiency and on efficiency of lubrication. For example, the data of the second German competition showed that the winning 100-horsepower Benz water-cooled engine, weighing 4.2 pounds per horsepower, consumed 0.472 pounds gasoline (thermal efficiency, 29 per cent), and 0.042 pounds oil, or a total of 0.514 pounds of both per horsepower hour. The 70-horsepower Gnome air-cooled engine mentioned in Bendemann's report, and weighing 2.9 pounds per horsepower, consumed 0.805 pounds gasoline and 0.253 pounds oil, or a total of 1.058 pounds of both per horsepower-hour. This being the case, the aggregate weight of the engine and supplies for different lengths of run up to 20 hours compare as follows, neglecting variations in tank weights that should add a little more to the engine of high consumption than to the more economical one. The radiator weight of the Benz engine is included:

Weights of engine, gasoline, and oil.

	For—				
	0 hours.	5 hours.	10 hours.	15 hours.	20 hours.
Benz.............................pounds..	4.2	6.77	9.34	11.91	14.48
Gnome.............................do....	2.9	8.19	13.48	18.77	24.06

Such relations as these—(Bendemann report shows the weights equalize in 1½ hours' operation)—lead to that most important conclusion derivable from all the competition test data in existence, viz, engines intended for short runs must be themselves light and need not be especially economical if, by sacrificing economy lightness is promoted. Conversely, engines intended for long runs must be economical at all costs, almost regardless of weight. It may also be added and this seems most significant that reliability is of importance about in direct proportion to the length of run, assuming good condition to be assured before starting in each instance, so that, again on the grounds of reliability, short run engines must be light even if less reliable, measured by period of uninterrupted operation, while to long-run engines considerable weight may be added to gain reliability.

From the design standpoint, a broad principle of practice can be directly derived, to the effect that aeroplane engines being intended for more and more widely varying types of service as to frequency of flights, length of run, and load-carrying capacity, need not be of one design, style, or type, but that different ones are justified and good engineering procedure demands the development and perfection to equal degrees, of as many different types and characteristics as will best serve the varying requirements of flight. From among these, a selection may intelligently be made for general service of undefined nature but with full forehand knowledge of its capabilities and limitations. All this agrees with engineering practice in other fields for there are to-day not only more different steam engines than ever before, but in any one group, such as locomotives, there is greater variety than there ever was; why, therefore, should anyone expect to find a single aeroplane engine or plan the development of

one type to the exclusion of others? To do so, is to assume that all flights in all flying machines are the same as far as engines are concerned, which is just about as true as the assumption that a good pleasure motor-boat engine is the right thing for a trans-Atlantic ship, or that the best power plant for a tramp freighter will properly serve a battle cruiser. To be sure there are certain elements of service peculiar to flight, to which all aero engines must be adapted, but this can not be interpreted to mean that all aeroplane engines must conform to one another in arrangement, performance, or even in materials throughout.

Returning to the factors of plant weight, study of which leads to such important conclusions as the preceding, it is worth while to examine more closely the separate influences of the several component factors of accessory and supply weights.

Radiator weights must vary with the amount of sheet metal, cooling surface of given material in kind and thickness. The purpose of this surface is heat dissipation to the air, so the number of square feet and its weight will vary directly as the jacket heat loss of the engine, and directly as the mean temperature difference between water and air, but inversely as the coefficient of heat transmission. The most reliable data on this amount of heat to be dissipated, in fact, the only data are given by Bendemann, who finds that contrary to most internal-combustion engines, including the automobile class, which give up between 30 and 40 per cent of their fuel heat to jacket water, aero engines conform pretty closely to 15 per cent of the heat of combustion given to and carried by the water to the radiator. The difference, 15 to 25 per cent, is either not taken up by the water from the combustion chamber at all, passing out in exhaust gases instead, or, being taken in part by the water, is dissipated directly from jacket and water pipes to the air. In formulating the rules of the German competition, the radiator weights were assumed to conform to automobile practice and taken at 0.13 pound per 1,000 British thermal units per hour, but the experiments indicate that this should have been about 0.4 pound per 1,000 British thermal units per hour. Taking the calorific value of gasoline at the round number of 20,400 British thermal units per pound and the consumption of the more efficient water jacketed engines as one-half pound per hour per horsepower, the heat supplied per hour per horsepower is 10,200 British thermal units, of which 15 per cent, or 1,530 British thermal units per hour must be dissipated by the jackets. This quantity with the constant of 0.4 pound per 1,000 British thermal unit hours would make the radiator weight 0.61 pound, per horsepower of engine. Comparing this with the radiator weight of the 61.6 horsepower Green (British) engine, winner of the Alexander prize competition, which had a total weight of 46.9 pounds, the actual unit weight of radiator and connections becomes 0.76 pound per horsepower of engine, a fairly good check, considering the wide differences of design and circumstances. Winkler puts radiator weight between 0.40 and 0.55 pound per horsepower.

It is perfectly well known how fundamentally dependent on the flow conditions of the air, on the air side, and on the presence of air or steam bubbles, on the water side, is the coefficient of heat transmission for such apparatus as radiators, and yet this subject has scarcely

been touched as a research problem, especially when it is considered that the mean temperature difference, another prime variable, is itself subject to considerable control. This will account for such differences in radiator weights as exist and is responsible for the belief that very material reductions may be expected in radiator weights following proper research or arrangements for securing rates of heat transmission and on thin noncorrosive metal inclosures.

Water weights are, of course, directly under control of the designer within certain limits, as the jacket spaces may be long or short, wide or narrow, pipes short and small or long and wide, and the water space in the radiator itself, almost anything. In the same 61.6 horsepower Green engine, winner of the Alexander prize, the whole water weight was 34.1 pounds, or 0.56 pound per engine horsepower less than the radiator weights. Winkler places this between 0.2 and 0.3 pound per horsepower. Other values for different engines are given in Table II to show the order of the magnitude of this factor.

Tanks for gasoline and oil will weigh more for large than for small supplies, but not in proportion to their volumes, as shape, thickness, and kind of material will determine the square feet of metal and weight of the tank per cubic foot of capacity as much as the volume. Other things being equal, that shape of tank will weigh least that has least weight per cubic foot of volume, and cylindrical tanks are most economical of metal weight, needing no stays, so the ratio of length to diameter is an important factor, which, however, also affects wind resistance, but these variations are not of such an order of magnitude to warrant detailed study here. The above-noted Green engine, 61.6 horsepower, and a gasoline tank of 70 gallons weighing 39.7 pounds, and a lubricating-oil tank of 6 gallons weighing 9.2 pounds, so that the net weights are, gasoline tank 0.65 pound and oil tank 0.015 pound per engine horsepower, or 0.57 pound per gallon for 70 gallons and 1.54 pounds per gallon for 6 gallons. Bendemann gives the round number of 0.2 pound tank weight per pound of gasoline or oil, which does not check the above figures. Tanks used in tests, he writes, are frequently too light for actual service, which indicates a necessity for standardizing tank-metal thickness, shape, and to some extent size, as large capacity may be just as well carried in several small tanks as in one large one and with better weight distribution on the frame, as well as affording a measure of safety.

Gasoline consumption for the better water-jacketed engines averages very closely 0.5 pound per hour per brake horsepower (B. H. P.), and for the rotating-cylinder air-cooled engines about 0.8 pound for full load, though, as might be expected, there are quite wide variations with type of engine and its condition as to cleanliness, adjustment, load, and speed. There is practically no data available on the rise of consumption with poor adjustment of carburetor, ignition, leaky valves or pistons, gumming bearings, carbonized combustion chamber, or even at speeds other than normal, or throttle positions other than wide open. It is not possible from test data to even approximate the gasoline consumption of an aero engine in actual flight service, though, judging from data on other classes of gasoline engines, it may easily be double this best value obtained by perfectly tuned new engines in competitive tests. We have many figures on total consumption of gasoline and oil during competition flights, but horsepower of course was not determined, and such figures must be com-

pared with each other to give a true picture of range of possible variation. Even here, however, the operators are skilled and on their mettle, so they may be expected to better ordinary everyday flight consumption. These engine-test figures may be translated into thermal efficiency approximately by taking the average calorific value of American gasoline at 20,400 British thermal units per pound, making the engine heat consumption for the two typical classes 10,200 British thermal units and 16,320 British thermal units per hour per brake horsepower, equivalent to $\frac{2545}{10200}=25$ per cent and $\frac{2545}{16320}=15.6$ per cent thermal efficiency referred to brake horsepower. With the actual consumption of the Benz engine of 0.472 pound, Bendemann reports a thermal efficiency of 29 per cent, which requires that the gasoline used have a calorific value of 18,900 British thermal units per lb., which is the value used by Güldner for European gasolines. Other figures indicate about an equivalent difference between the American and European fuels which could be accounted for by the prevalence of paraffins and olefins, respectively, in each, even if of equal density.

Such a thermal efficiency as this high value is truly remarkable, and under the condition of operation and size of aero engines can hardly be bettered, judging from other experiences and from fundamental conditions to be examined later, but the low value is too low to be tolerated without adequate compensating advantages in engine weights for short flights and in the reliability and adaptability factors. Actual test values for specific engines and tests are reported in the appendix and need not be detailed here, but attention is again called to the practical importance of consumption data on other than these best conditions to show not only how high it may be in service, but also how sensitive it is to each individual adjustment and operating condition that may exert an influence.

Oil consumption is a thing that seems to follow no particular law, however much may be known about contributory circumstances, such as chemical character, viscosity, mode of application, surface speed, pressure and temperature, air evaporation, combustion chamber carbonization and cracking, and exhaust discharges. Beyond the more or less general adoption of castor oil to avoid gasoline absorption in the crank cases of rotating-cylinder aero engines, and the use of most widely different systems of feed and bearing conditions, this is a practically wide-open field of research. In all the competition tests the oil consumption has been made a subject of measurement, but no analysis of causes of consumption has been made, nor are there any data on the relative consumption of different oils or of different oiling systems for a given engine. The figures must be taken for no more than they really represent, viz, what was used, but it can be assumed that they are no guide whatever to the oil that will be consumed in actual service, except when consumption is fixed by a pump plunger displacement. Nor do these figures aid in fixing the least value attainable after proper thorough research on the lubrication of a given engine, which is rather more a matter of reliability and engine life than of oil weight to be carried. In the German tests values were found ranging from 0.009 pound to 0.089

pound per hour per brake horsepower for the water-cooled engines and from 0.145 to 0.253 pound per hour per brake horsepower for the rotating air-cooled cylinder engines. The only conclusions derivable from these figures are that there is a very wide variation—about 25 to 1—proving the need of study, and that on the whole the rotating air-cooled cylinders are much greater oil consumers than the fixed water cooled.

The aggregate weight of all the units of the power plant, engine, engine accessories, and supplies can be represented algebraically or graphically with every element involved in correct relative magnitude. All of these weights are constants for each engine, except the gasoline and oil weights, which are products of consumption per hour and the length of the run. Accordingly, the graphic representation will be a series of straight lines or of the aggregate, a single straight line. Algebraically the equation of that line will contain two constants, each of which is the sum of similar constants, one representing intercepts on the axis of zero time and the other slopes. In order to keep the various elements of the aggregate weight distinct and to bring out clearly the big factors of weight of engine proper and of gasoline weights, it is desirable that the excellent arrangement of a single line for each engine used by Bendemann in the second German report be supplemented by a general equation involving all the constants and a table of values for each as derived from the tests. Such an equation will have the following form:

$$\left.\begin{array}{l}\text{Weight of plant complete with}\\ \text{tanks full for } H \text{ hours' run,}\\ \text{pounds per horsepower.}\end{array}\right\} = \left\{\begin{array}{l}\text{Weight of engine alone per horsepower.}\\ +\text{Weight of gasoline tank per horsepower.}\\ +\text{Weight of oil tank per horsepower.}\\ +\text{Weight of radiator per horsepower.}\\ +\text{Weight of water per horsepower.}\\ +\text{Weight of muffler.}\end{array}\right.$$
$$+\left\{\begin{array}{l}\text{Pounds gasoline per hour per horsepower}\\ \text{Pounds oil per hour per horsepower}\end{array}\right\} H.$$

Symbolically this takes the following form with corresponding meanings from the former equation:

$$W = W_e + W_{gt} + W_{ot} + W_r + W_w + W_m + (G+O)H$$

In the following Table II are given some typical values for these seven constants, derived from the tests and for the total W for 0 and 10 hours. The gasoline and oil weights are added for 15 and 20 hours, but the plant weight can not be so given because of the uncertainty of the tank weights, which naturally are not directly proportional to content weights. It is interesting to note, however, that in 10 hours the plant weight is doubled—that is, the supplies for that time equal the weight of the plant empty for water cooled fixed cylinder engines. The air cooled rotating cylinder engines in the same time of 10 hours more than quadruples the weight.

TABLE II.—*Weights of engine accessories and complete plant weights per horsepower versus type construction.*

Name and authority.	Engine alone.	Gasoline tank.	Oil tank.	Radiator and connections.	Water.	Muffler.	Total engines and accessories.	Gasoline per hour.	Oil per hour.	Gas and oil for 5 hours.	Gas and oil for 10 hours.	Plant and supplies for 10 hours.
Average values, Bendemann	......	(1)	(2)	0.63		......	......	......	......	......	......	......
4-cylinder 100-horsepower Benz, Bendemann	3.57	0.944	0.084	.626		......	5.224	0.472	0.042	2.57	5.14	10.364
6-cylinder 90-horsepower Daimler, Bendemann	3.75	1.02	.076	.626		......	5.472	.510	.038	2.74	5.48	10.952
4-cylinder 70-horsepower Daimler, Bendemann	4.29	1.01	.094	.626		......	6.020	.505	.047	2.76	5.52	11.540
4-cylinder 100-horsepower Daimler, Bendemann	4.29	.988	.080	.626		......	5.984	.494	.040	2.67	5.34	11.324
4-cylinder 70-horsepower Daimler, Bendemann	4.74	1.006	.062	.626		......	6.434	.503	.031	2.67	5.34	11.744
6-cylinder 100-horsepower Daimler, Bendemann	4.60	1.056	.062	.626		......	6.344	.528	.031	2.99	5.99	12.33
4-cylinder 60-horsepower Daimler, Bendemann	4.89	1.002	.058	.626		......	6.576	.501	.029	2.65	5.30	11.876
4-cylinder 65 horsepower Daimler, Bendemann	5.09	.998	.120	.626		......	6.834	.499	.060	2.79	5.59	12.424
4-cylinder 95-horsepower N. A. G., Bendemann	4.33	.970	.076	.626		......	6.002	.485	.038	2.61	5.23	11.232
4-cylinder 55-horsepower N. A. G., Bendemann	4.36	1.038	.018	.626		......	6.042	.519	.009	2.64	5.28	11.322
4-cylinder 95-horsepower Argus, Bendemann	3.77	1.060	.178	.626		......	5.642	.534	.089	3.11	6.23	11.872
4-cylinder 70-horsepower Argus, Bendemann	4.38	1.176	.166	.626		......	6.34	.588	.083	3.35	6.71	13.058
6-cylinder 100-horsepower Argus, Bendemann	4.60	1.172	.134	.626		......	6.532	.586	.067	3.76	6.531	13.064
6-cylinder 100-horsepower Mulag, Bendemann	5.14	1.056	.042	.626		......	6.864	.528	.021	2.74	5.49	12.354
6-cylinder 90-horsepower Schröter, Bendemann	4.65	1.242	.094	.626		......	6.612	.621	.047	3.34	6.68	13.292
6-cylinder 125-horsepower (Hall-Scott makers)	4.32	......	......	.51	.32	......	......	.60	.03	......	......	......
Average of 6, British (Anzani, maker)	3.7	......	......	......	......	......	......	.54	.164	......	......	......
6-cylinder 87-horsepower (Benz, maker)	4.0	......	......	......	.138	.101	......	.557	.022	......	......	......
6-cylinder 60-horsepower (Wright, maker)	5.1	......	......	......	......	......	......	.53	......	......	......	......
Austro-Daimler "Flight"	......	......	......	{[3] .616, [4] .589, [5] .474}	......	......	......	......	......	......	......	......
Green, Alexander test	5.48	.65	.15	.76	.56	......	7.60	.59	.175	......	7.65	15.25
Gnome, 1913, Lumet	......	......	......	......	......	......	3.366	.849	.255	5.520	11.04	14.41
Gnome, 1911, Lumet	......	......	......	......	......	......	2.88	.805	.253	......	10.58	13.46

[1] 20 per cent of fuel weight
[2] 20 per cent of oil weight.
[3] In 65 horsepower.
[4] In 90 horsepower.
[5] In 130 horsepower.

NOTE.—Plant weights are given without muffler.

Typical arrangements of cylinders, pistons, jackets, frames, crank shafts, valves, valve gear, and typical structural forms of each, have been produced in great variety and in considerable numbers. Of these a fair number have received more or less development work, but the majority of them must be regarded as hardly more than interesting proposals, or experiments in need of development work to definitely reject or retain them for use. Features of detail will be treated later in the course of the analysis of the engine after a review of the types classified by general arrangement.

Most of the engines operate on the four-stroke cycle, though the two-cycle system is represented, both air and water cooling is used, and of the air-cooled class there are representatives of self-cooling by rotation of cylinders, by fan circulation and by propeller blast, or

free air currents over fixed cylinders. All engines are multicylinder, four or more, and generally more, and while nearly all use horizontal shafts with direct or spur-gear propeller drive, the vertical shaft with bevel-gear drive of propeller is represented.

These types, classified by cylinder and crank arrangement, are as follows:

1. Automobile type, four or more cylinders in line, each with its own crank, cylinder heads up. Air or water cooled.
2. V type, two rows of cylinders of four or more each, inclined to each other, one crank for each V pair of cylinders. Air or water cooled.
3. Radial star rotating cylinders, with crank shaft fixed, or rotating in the same or opposite direction. Air cooled only.
4. Special arrangement or combinations of the preceding.

Of these classes the first three are the most typical of the aero engine art in point of numbers of representatives, amount of development work done on them, and of standing in the engine-building industries of the firms represented, as will be seen from the following list of names of engines and makers, Table III, arranged under each class heading. This is not to be regarded, however, as a criticism of any of the other classes.

TABLE III.—*Aero engines by classes.*

Class No.																				
I.			II.						III.			IV.								
Cylinder crank arrangement.																				
Fixed in line.			Fixed V, 2 cylinders per crank.						Rotary.			Fixed star.						Miscellaneous.		
Cooling.																				
Water.			Air.			Water.			Air.			Air.			Water.			Air.		
Engine or maker.																				
Benz.			De Dion Bouton.			Curtiss.			B. M. & F. W.			Anzani.			Two-cycle laviator.			Ashmusen.		
Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.
1,013	4	1,288	80	8	1,800	75 100 160	8 8 8	1,100 1,250 1,100	37.5	7	1,031	25 30 40	3 3 6	1,250	80	6	1,300	105	12	1,800
Daimler.			Renault.			Sturtevant.			Gyro.			Anzani.			Salmson.					
88.9	6	1,387	70	8	1,800	140	8	2,000	38.8	7	954	50 60 70	6 10 10	1,250	90 135 200	7 9 14	1,250	....	....	....

TABLE III.—*Aero engines by classes*—Continued.

Class No.																				
I.			II.						III.			IV.								
Cylinder crank arrangement.																				
Fixed in line.			Fixed V, 2 cylinders per crank.						Rotary.			Fixed star.						Miscellaneous.		
Cooling.																				
Water.			Air.			Water.			Air.			Air.			Water.			Air.		
Engine or maker.																				
Daimler.			Wolseley.			Sunbeam.			Old Gnome.			Anzani.			Salmson.					
Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.
71.3	4	1,412	82	8	1,650	225	2	2,000	49	7	1,194	80 100 125	10 10 10	1,250	150 300	9 9	1,250 1,200	....	....	....
Daimler.						Sunbeam.			Old Gnome.			Anzani.								
99.2	4	1,373	....	....	....	150	8	2,000	62.9	7	1,156	200	20	1,250	....	....	....	....	....	....
Daimler.						Ransenberg.			Gnome.			2-cycle laviator.								
70.4	4	1,343	....	....	....	150	8	1,200	50 60 80	7	120	50	6	1,200	....	....	....	....	....	....

Daimler.						Clerget.			Gnome.			Edelweiss.								
108.1	6	1,315	......	......	......	200	8	1,300	100 100 160	9 14 14	1,200	75 125	6 10	1,350 1,350	......	......	......	......	......	......
Daimler.						Leviator.			Gnome.											
60	4	1,396	......	......	......	80 120	8 8	1,200 1,200	200 80 100	18 7 9	1,200	......	......	......	......	......	......	......	......	......
Daimler.						Panhard-Levassor.			D'Hénain.											
66.5	4	1,391	......	......	......	100	8	1,500	50	7	......	......	......	......	......	......	......	......	......	......
N. A. G.						Wolseley.			Clerget.											
95.7	4	1,344	......	......	......	130	8	1,200	50 80	7 7	1,180 1,180	......	......	......	......	......	......	......	......	......
N. A. G.									Demont.											
55.8	4	1,408	......	......	......	......	......	......	300	6	2,000	......	......	......	......	......	......	......	......	......
Argus.									E. J. C.											
98.7	4	1,368	......	......	......	......	......	......	60	6	2,000	......	......	......	......	......	......	......	......	......
Argus.									Esselbé.											
71.0	4	1,342	......	......	......	......	......	......	65	7	1,250	......	......	......	......	......	......	......	......	......

TABLE III.—*Aero engines by classes*—Continued.

Class No.																				
I.			II.						III.			IV.								
Cylinder crank arrangement.																				
Fixed in line.			Fixed V, 2 cylinders per crank.						Rotary.			Fixed star.						Miscellaneous.		
Cooling.																				
Water.			Air.			Water.			Air.			Air.			Water.			Air.		
Engine or maker.																				
Argus.									S. H. K.											
Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.
102.1	6	1,370	......	......	......	......	......	......	70 90	7 7	......	......	......	......	......	......	......	......	......	......
Mulag.									S. H. K.											
101.6	6	1,396	......	......	......	......	......	......	140 180	14 14	......	......	......	......	......	......	......	......	......	......
Schröter.																				
88.9	6	1,252	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......

Hall-Scott.																				
125	6	1,300																		
Austro-Daimler.																				
90 120	6	1,300 1,200																		
Wright.																				
60	6	1,400																		
Sturtevant.																				
100	4	2,000																		
Green.																				
100	6	1,250																		
Clerget.																				
50 100	4 4	1,450 1,300																		
Chenu.																				
65 90 100 250	4 4 6 6	1,800 2,300 1,600 1,500																		

TABLE III.—*Aero engines by classes*—Continued.

Class No.																				
I.			II.						III.			IV.								
Cylinder crank arrangement.																				
Fixed in line.			Fixed V, 2 cylinders per crank.						Rotary.			Fixed star.						Miscellaneous.		
Cooling.																				
Water.			Air.			Water.			Air.			Air.			Water.			Air.		
Engine or maker.																				
Argus.									S. H. K.											
Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.	Horse-power.	Number of cylinders.	Revolutions per minute.
102.1	6	1,370	......	......	......	......	......	......	{ 70 90	7 7 }	......	......	......	......	......	......	......	......	......	......
Mulag.									S. H. K.											
101.6	6	1,396	......	......	......	......	......	......	{ 140 180	14 14 }	......	......	......	......	......	......	......	......	......	......
Schröter.																				
88.9	6	1,252	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......

Hall-Scott.																				
125	6	1,300																		
Austro-Daimler.																				
90 120	6	1,300 1,200																		
Wright.																				
60	6	1,400																		
Sturtevant.																				
100	4	2,000																		
Green.																				
100	6	1,250																		
Clerget.																				
50 100	4 4	1,450 1,300																		
Chenu.																				
65 90 100 250	4 4 6 6	1,300 2,300 1,600 1,500																		

CLASS 1.—*Automobile class.*

Water cooled:
- American—
  - Hall-Scott.
  - Sturtevant.
  - Wright.
- German and Austrian—
  - Mercedes (Daimler).
  - Austro Daimler.
  - Benz.
  - N. A. G.
  - Argus.
  - Mulag.

Water cooled—Continued.
- German and Austrian—Continued.
  - Schroeter.
  - Basse & Selve.
  - Flugwerke Deutschland.
- French—
  - Clerget.
  - Chenu.
- British—
  - Argyll.
  - Green.

CLASS 2 V.

Water cooled:
- American—
  - Curtiss.
  - Sturtevant.
  - Ransenberger.
  - Maximotor.
- French—
  - Panhard-Levassor.
  - Clerget.
  - Laviator.

Water cooled—Continued.
- British—
  - Sunbeam-Coatalen.
  - Wolseley.

Air cooled:
- French—
  - Renault.
  - De Dion-Bouton.
- British—Wolseley.

CLASS 3.—*Radial start rotating air cooled.*

American: Frederickson.

German:
- Kruk.
- Hirch.
- R. E. P.
- B. M. & F. W.

French:
- Gnome.
- Clerget.

French—Continued.
- Canda.
- Burlat.
- Helium star.
- Demont.
- D'Henain.
- E. J. C.
- Esselle.
- S. H. K.

CLASS 4.—*Specials.*

Radial star-fixed cylinders:
- French—
  - Salmson, water cooled.
  - Laviator, two cycle.

Opposed fixed cylinders:
- American—Ashmusen.

Squirrel-cage cylinders:
- French—Edelweiss.

Radial fan:
- French—Anzani.

Inverted automobile:
- German—Daimler.

Many engines appearing in older lists are omitted, because of the belief that they are now superseded or abandoned, and likewise, some new engines now in existence are not mentioned because of lack of general acceptance as commercial. It may be, and is quite likely, that errors have been committed in these insertions and omissions, but this is inevitable without personal visits to the engine shops, which, in the present instance, were quite impossible.

REPORT No. 7.

PART 2.

AERO ENGINES ANALYZED WITH REFERENCE TO ELEMENTS OF PROCESS OR FUNCTION, ARRANGEMENT, FORM, PROPORTION AND MATERIALS, AND THEIR BEARING ON THE POWER-WEIGHT RATIO, RELIABILITY AND ADAPTABILITY FACTORS.

By Charles E. Lucke.

Part 2 (a).—AERO ENGINE PROCESSES AND FUNCTIONS OF PARTS VERSUS POWER-WEIGHT RATIO, RELIABILITY, AND ADAPTABILITY FACTORS.

In any machine the process is of superior importance to the mechanism as the latter is but one of many possible means for the execution of the former, and however necessary it may be to have the mechanism adapted in form, proportion, arrangement, and materials, to its objective process, success of the machine is fundamentally dependent on the process itself. Most machine processes are really combinations of a series of separate individual process steps working together, just as the mechanism parts themselves coact, and these processes are commonly said to be similar when they consist of the same partial steps executed in the same order as a series, and machines executing them are regarded as belonging to the same class, or as similar machines. There are, however, very great differences to be found in these similar machines which, therefore, may be vastly dissimilar from other standpoints. In the first place the process steps may differ widely in degree though being identical in kind, and this difference in degree may be in turn responsible for very considerable differences in mechanism. No better illustration is available than the common piston steam engine in which one basic step is expansion of steam after admission and before exhaust, yet experience has developed a whole succession of valves and valve gears, some adapted to moderate and others to high expansion ratios, while expansion to pressures below atmosphere immediately calls for the condenser with its elaborate series of auxiliary appliances and pumps. Differences in mechanism may be almost infinite even though the same process is executed, and to the same degree, and the steam engine will again serve as an illustration. Such differences may be significant or not. They must be regarded as significant when some good purpose is served whether the differences are those of detail parts form such as the shape of a piston; of arrangement of the same typical parts, such as the locomotive engine as compared with that of the steamship; of proportion of parts, as diameter of cylinder or thickness of wall; or of material. Such differences as are now accepted and well

understood in the steam-engine field can all be analyzed into significant or indifferent from the standpoint of service requirements. These service requirements require years of experience to be appreciated to a degree that permits of a reduction to standards of practice in arrangement, form, proportions, and materials of the mechanism and its parts. Even after the establishment of such experience standards of practice for machines performing a definite fixed service there will always remain very considerable differences of the indifferent or nonessential order.

Aero engines, while belonging to the now large and established class of internal-combustion engines, and to the smaller fairly well-developed subclass of the gasoline carburetor internal-combustion engine, in which the farm, automobile, and boat types are most fully developed, are themselves still struggling through the development stage, due to the youth of the special service to be performed, and in spite of all that might be borrowed from the older most similar arts. In fact there is some evidence that these older arts have exerted a distinct retarding influence even where assistance might be expected, because borrowing is the easiest mode of acquisition. It is not unnatural to find automobile practice being adopted for aero engines, when it is not yet clear that there is anything required of the aero engine sufficiently different from what the automobile or boat engine can supply, to make the latter unsuitable for the service of the former. At the same time there is equally strong evidence that in some respect the differences in service requirements have been exaggerated or misinterpreted with the result that totally different engines were produced unlike anything before built, and yet just as unsuitable as the borrowed auto or boat engine.

In proportion as service requirements on the one hand become better understood, and as engine capabilities or limitations, on the other hand, are recognized and utilized, so will the aero engine as a type come into full growth. Review of the engines so far proposed, built, and tried out, indicates a strong trend in some directions, but just as surely proves that in most essentials the period of blind grasping at every possibility whether rationally defensible or not, has not yet come to an end. The most hopeful sign of progress is the now general recognition that no older type of engine can be borrowed bodily for aero service, and following this, the large number of suggestions for modification that have been and are now being made, some rational, derived through reasoning from fact data, but often without any recommendation other than mere purposeless difference.

Most of the rational development so far accomplished has been devoted to forms of the type parts, to their grouping or general arrangement, and to special materials for their construction, rather than to the processes that are fundamental to the gasoline carburetor type of internal combustion engine. Aero-engine designers being so intensely absorbed in the problems of arrangement of parts, adaptation of form of parts, reduction of metal thickness and application of materials of high elastic limit or low specific gravity, have in some instances, though fortunately not all, been diverted from thought of the process steps to be executed, in kind and degree. This becomes clear by comparisons, first of aero engines with each other and second of any one engine with the absolute standards of thermodynamics.

It is clear that if at the same speed and using the same fuel one engine gives a materially higher mean effective pressure than another, or a lower specific fuel consumption, then some elements of the thermodynamic process have been violated by the mechanism of the inferior machine. It is also true that if the thermal efficiency obtained is a smaller fraction of the thermodynamic limit of possibility than in an auto engine, for example, then again something has been incorporated in the aero-engine structure inferior to its counterpart of the auto engine structure. To a lesser degree similarly, if aero-engine stoppages not due to seizure of bearings or breakage of parts are more frequent than in auto engines, or even if they stop at all under these conditions, then the process requirements are in some way being violated by unsuitable mechanism, for if they were not the engine would continue to run, and without change. As a matter of fact, the whole question of reliability is one of maintenance or continuity of the process in every stage, assuming, of course, an absence of the pure mechanism troubles of breakages or bearing failures. Likewise, some of the elements of the adaptability factor, as well as those of reliability or of high power and fuel efficiency, are concerned with the process, for, should excessive tilting of the engine interfere with the carburetor action and result in poor mixtures, or should passage through a cloud or fog obstruct the intake with frost or ice, or should flights at excessive altitudes change the mixture, then the engine becomes inoperative by reason of process interference due to lack of adaptability of the mechanism to the maintenance of the process when subjected to the ordinary interference of actual use peculiar to air flight.

Proper execution of the processes by mechanism that insures its continuity in kind, and the constancy of every step, in degree, regardless of any interfering conditions incident to normal or even extraordinary aerial use, is a necessary prerequisite to the high mean effective pressure and high thermal efficiency that together make for low power plant weight per horsepower for any length of flight. It is just as essential to the continuity of operation and output that constitutes reliability, entirely independent of whatever contribution may be obtained to the same end, from variation of general arrangement, and detail design of parts as to form or thickness or from the selection of special materials.

The processes are comparatively simple and easy to state, though a thorough analysis of the relative or absolute perfection of execution that various designers have accomplished through their mechanism would require far more space than is available here. Such an analysis must moreover be based on far more test data than have even been made available anywhere. Judging from the literature of the subject and from some familiarity with general practices not so recorded, it can be stated that practically no work has been done except by a few large engine building concerns who keep their results secret, and comparatively speaking, no data obtained bearing directly on the execution of the process steps, and the effect of design on process, for aero engines, though some interpretation can be based on the few overall results of engine tests. While the details of design versus process are beyond the scope of this report, it is possible even from a statement of the processes and their fulfillment conditions, to derive some general specifications for the parts of the apparatus that, taken

together, make up the power generating part of the engine, as distinguished from those parts that merely transmit or support.

As the working medium is primarily an explosive mixture of air and the vapor of gasoline, the first broad process step is mixture making, preparatory to introduction into the cylinder unless it be made directly therein. This must be followed by the second step of suitable treatment of the mixture in the cylinder, including expulsion of burnt products. Finally, as combustion develops heat in contact with metal walls, continuity of operation or the maintenance of a steady state in all respects requires heat abstraction and dissipation to a degree and at a rate equal to that of heat reception, so the third broad process step is cooling.

Each of these three broad divisions of the general power generating process, mixture-making, cylinder treatment of mixture, and combustion chamber cooling is itself a process, and is in turn subdivisible into more detailed or subprocesses, each definable to some extent as to degree or range that it is desirable to maintain.

The mixture-making process starts at the point of supply of gasoline and air and ends at the intake port of each cylinder. The one exception to this used in a few engines is the making of mixture directly in the cylinder by pump injection of gasoline, a method so wholly unsuited to the small cylinder high-speed engine, with such volatile fuel as gasoline, as to be rejected without further discussion not only on rational grounds but on actual comparative experience with the now standard system of mixture making. This standard practice that has taken many years to establish recognizes mixture-making as a distinct function to be carried out external to the cylinders, so as to permit of some control of this independent function without the interference that must result when it is combined with others in a single apparatus part.

Applying the common but more or less inaccurate name of carburetion, to this mixture-making function because the principal structural element of the process is the carburetor mechanism, the process divides itself into (*a*) fuel supply; (*b*) air supply; (*c*) carburetion proper, which includes proportioning, mixing, and vaporizing, and (*d*) mixture distribution to cylinders. Each of these steps must be carried out without variation in spite of anything that might happen beyond extraordinary accidents, and the apparatus, mechanism, or equipment must be so constructed as to insure the results desired. This is by no means easy, as will appear from even a superficial analysis of conditions and possibilities. Air must be taken from the atmosphere through which the machine is moving at a high, though not constant speed, a speed so high that the air pressure equivalent to the velocity, or velocity head of the air, is quite appreciable. With the air intake opening pointing in the direction of travel the velocity head is added to the static pressure of the air and air flow necessarily varies with flight speed, though it should not. This might be avolded by suitably shaped entrance orifice, the plane of which is in the direction of flight, but this is no safeguard when turning or in side gusts. The first requirement of air intake must, therefore, be independence of flow of air with reference to direction and speed of motion. Atmospheric air varies in absolute pressure with altitude and likewise varies in temperature, in water vaporized, and suspended water such as fog or rain. Each of these things exerts separately and together an

influence on carburetion. Temperature, pressure, and moisture affect air density and hence the flow through the air orifice under a given pressure drop. Temperature affects the vapor pressure of the gasoline. (Absolute pressure affects air flow itself independent of the density change.) Vaporized moisture affects the accumulation of water in the mixture passages due to reduction of temperature incident to gasoline vaporization, and both vaporized and suspended moisture affect the accumulation of ice in the mixture passages, unless heat be added in sufficient degree. These things need hardly be stated to be accepted as fundamentally important and as necessary elements for incorporation directly or indirectly into specifications for the air supply to the carburetor. The carburetor action should be made quite independent of these variables and it must be sufficiently independent to prevent changes of mixture quality beyond the allowable working range. Therefore, however great a variation may be encountered during actual flight, in direction and velocity of flight or wind, in barometric pressure, in atmospheric temperature, in atmospheric moisture vaporized or suspended as well, the mixture quality must be kept within the two limits to be determined as necessary to continued engine performance.

Gasoline must be carried in a closed tank and must be fed to the carburetor through a pipe, and the supply to the carburetor should be quite independent of the direction and angle of inclination of the whole structure. It positively must be unaffected by such changes of relative position of tank and carburetor, as may be due to not only ordinary but even extraordinary or emergency turning, gliding, climbing, or temporary falling movements of the whole machine. If the machine should completely fall and upset, the gasoline should be prevented from running out on the hot exhaust pipe as this is likely to cause a fire. Gravity feed from tank to carburetor is affected, as to head, by every variation in angle and direction of inclination of the frame. Gravity feed tanks must have an air vent and so if overturned the vent becomes a spill hole unless a special check feature be added. In stationary plants gravity feed from supply tanks is forbidden by the fire underwriters' regulations because of the possibility of drainage of the whole tank due to a leak in any part of the pipe system. Air or gas derivable from fire-charged bottles, from pumps, from combustion chamber relief valves, or from exhaust back pressure acting on the liquid surface in depressed gasoline tanks will feed the gasoline from any relative position of tank and carburetor. If reasonably high pressures are used in comparison with the normal static gasoline head, the delivery pressure will be substantially constant at all inclination angles and spilling will be confined to the small carburetor float chamber as the main tank is closed. This system is in quite general use in auto practice. Pump feed from a main depressed tank with air vent to a small auxiliary gravity tank with overflow return directly above the carburetor, is the standard stationary system. Recently automobile practice has adapted this to its service requirements, replacing the pump and overflow return by a vacuum lift system operated from the suction header beyond the throttle, but retaining the depressed main tank with air vent and the small auxiliary gravity tank without air vent, which being so close to the carburetor can supply it at all times at substantially constant head. These two systems of pump and suction header lift may be operated

with a closed main tank if slightly modified and in the event of a leaky pipe no loss or fire can occur because instead of gasoline escaping air flows in, doing no harm if the leak is small, but stopping the supply without loss if the leak is large.

The extraordinary changes of motion in direction and speed, both horizontally and vertically, peculiar to the aeroplane introduce liquid inertia and centrifugal pressures which may accelerate or retard gasoline flow by raising or lowering the pressure at the point of delivery to the carburetor. This is a peculiarity of the aero-engine service conditions which requires special attention. To cover all these influences an additional specification may be added for the carburation system; the fuel tank, piping, and supply system must deliver fuel to the carburetor at pressures that do not vary enough to cause the mixture quality to vary beyond the limits required for the proper steady operation of the engine regardless of angularity of the machine or of changes of its motion as to direction or velocity, and they must be such as to prevent fuel loss from small leaks and to minimize any spilling when overturned, preventing whatever spills touching hot parts or reaching electric sparks. References to the literature are made for actual tank arrangements which require no comment here except the approval of the practice of using more than one tank and especially of installing a small emergency reserve tank holding enough to insure a safe landing after main tanks are empty.

When supplied with atmospheric air and with fuel under pressure or static head, the carburetor mechanism is supposed to make a proper explosive mixture and through intake header and branches to deliver to each of the several inlet valves identical charges of that mixture equal in quality and quantity. This is supposed to happen regardless of the total quantity of mixture required by the engine load or speed and regardless of any variation in air temperature, pressure, moisture, direction, and velocity of flight or fuel delivery pressure. The possibilities of success in attaining this mixture-making ideal must, of course, depend on the definition of proper mixture, for in this is to be found the allowable range of variation from absolute constancy of quality.

Mixtures that enter the cylinder with too much gasoline for the air to support in combustion will not be explosive if the vaporized fuel excess is large enough and with such mixtures the engine is inoperative. Long before such a great fuel excess as this is reached the engine may be operative yet operate badly. It is clear that any excess vaporized gasoline in the mixture can not burn, so it will decompose or carbonize, depositing carbon all over the combustion chamber, including spark plugs and piston head, and show in exhaust as smoke. Such a mixture will be operative for a time, such time as it takes for the carbon to accumulate in layers thick enough to glow on hot spots, such as piston heads, causing back fires or preignition and possibly short circuits and miss fires from collections on spark plugs if they are so designed as not to be self-cleaning. Carbon deposits will also cause piston rings to stick and leak and impair lubrication when it collects on cylinder walls and between rings. To be sure, a certain amount of just such carbonization can be traced to lubricating oil that works past pistons, but this is an independent matter to be separately treated by oil selection and supply system. Excess fuel in the liquid state may be present when the vaporized

part and the air make a proper mixture, and such excess will partly decompose as above, but part will be dissolved by the lubricating oil and defeat lubrication besides being a dead loss.

Excess vaporized gasoline in the mixture should be prevented, first, to prevent carbonization, but also to avoid the slow combustion that results when the excess is too great. A small excess gives the highest rate of combustion and high rates of combustion are necessary in aero engines to permit of attaining the highest initial cylinder pressures with the very high mean piston speeds in use, none of which are below 1,000 and some in excess of 2,000 feet per minute. By use of properly high compression and more than a single point of ignition a sufficiently high rate of combustion appears to be obtainable without resorting to such overrich mixtures with their carbonizing evils and direct waste of fuel. It may therefore be set down as a requirement that mixtures preferably should not contain any excess fuel at any speed and load, and positively must not contain enough to cause carbon accumulation, measurable fuel waste, or interfere with lubrication.

It goes almost without saying that mixtures of air and fuel must be homogeneous and uniform throughout; that is, the constituents must really be mixed. On reaching the cylinder at least, no liquid should remain unvaporized, or, to use a short word, the mixture should be dry. A correct overall ratio of gasoline to air by weight as required for combustion reaction will not serve the purpose if the gasoline is in liquid form, or even if it is vaporized, but all concentrated in one corner of the combustion chamber with pure air in some other corner, such as is sure to happen with direct injection or with more unvaporized liquid admitted past the inlet valve than can be vaporized while entering. Such nonhomogeneous and wet mixtures will both carbonize and cut lubrication even if total weights are correctly related, so the second and third requirements of mixture must be homogeneity, and dryness at least after admission.

Other things being equal, a cool mixture carries more heat per cubic foot and hence more work capacity than a hot mixture of the same fuel and air. But with liquid fuel, mixtures that are too cold are no mixtures at all, any more than a brook running through the country can be said to be mixed with the atmosphere, though rain by a stretch of the imagination might be, and a fog really is, though not so intimate a mixture as vaporized moisture. Any gasoline-air, kerosene-air, benzol-air, or alcohol-air mixture, in combining proportions may be dried if the temperature be high enough and the temperature required will be least for the fuels of greatest vapor pressure of their heaviest constituent if they are solutions of heavy and light parts, as is the case with the petroleum distillates. For any one fuel the required drying temperature is least the more intimately the air and fuel are mingled or stirred, so that any fuel particle will be required to exert only the partial pressure of the vapor in the final mixture, instead of the full mixture pressure of one atmosphere that is necessary without true mixing. Mixtures should, therefore, be as cool as possible consistent with dryness and the maximum permissible moisture is that which will vaporize on entrance. The higher the mixture pressure the greater the work capacity of the charge, so that everything that contributes to such must be promoted as much as the preparation of cool and otherwise proper

mixtures. This means in effect that the pressure drop between the air and the cylinder must be a minimum, but this is entirely a question of proportions of passages.

Finally with reference to mixture quality there can not be much excess air, preferably none. Of course, excess air can not cause carbonization or lubrication trouble; in fact, it exerts a beneficial influence tending to burn accumulated hot carbon or lubricating oil vapor, and it permits of a somewhat higher compression which improves economy. But all the explosive mixtures of hydrocarbon vapors and air become nonexplosive in ratios very close to the combining proportions on the excess-air side, and with even a slight air excess the rate of combustion becomes prohibitively low. Summarizing mixture-quality requirements, a mixture is proper when it has the least and preferably no excess of either air or fuel, when it is homogeneous, when it is dry after entrance and as cool as possibly consistent with homogeneity and dryness, and when it is supplied at the maximum absolute pressure. To produce such mixtures is the function of the carburetor.

Carburetor mechanisms capable of making mixtures of such specified quality under the previously noted conditions of air and fuel supply are practically nonexistent at present, and improvement can hardly be expected so long as carburetor production remains a separate business, and purchasers buy on name instead of on performance, as is the practice, selling on name only, at present in the motor-car and motor-boat industries. Not until the aero-engine producer develops carburetor specifications in terms of mixtures produced and testing appliances to prove fulfillment and to locate causes of nonfulfillment of each separate requirement can the needed mixture-making carburetor be obtained. Under these conditions it matters very little whether the aero-engine builder makes his own, or buys on guaranty of performance, independent of engine operation.

Very great progress has been made in recent years in carburetor design for automobile and marine engines, but the end has not been reached, because all data point to a failure to maintain the quality of mixture in all the specified respects. In some respects the problem is less difficult with the aero engine than with the auto, as the former is not subjected to as wide a range of flow rates nor to such sudden and frequent changes in flow rates as are the latter, due to automobile driving in dense traffic or over country roads with constant changes of grade, curves, and rough spots requiring continuous opening and closing of the throttle. This fact is responsible for the general practice among aero engine builders of buying stock automobile carburetors on the theory that, the service being less severe, they should work better on aero service; yet such a conclusion is not warranted. While it is true that flow rate fluctuations will not be so great and so cause less variation in proportions, it is also true that the normal condition of flying with feed throttle wide open or nearly so produces a more intensive temperature drop, reducing vapor pressure and decreasing the degree of gasoline vaporization or increasing mixture wetness and condensing or freezing more water. It is also true that far stronger variations of fuel and air supply conditions must be encountered in air flight than in road driving. What is still more significant, however, is the fact that the aviator has no such opportunity to make hand adjustments as has the chauffeur, nor are the

consequences of auto-engine stoppage due to bad mixture hardly more than annoyance, while such a stoppage of an aero engine may mean a complete wreck. It can not be too strongly stated that acceptance for use of standard carburetors on their names, or even reputation, is not a satisfactory practice for aero engines. They should be designed or purchased to specifications of maintenance of mixture quality under all variations of working conditions within possible ranges to be met with in service.

There seems to be no doubt after the years of experience in carburetor construction for automobiles and boats that the gasoline float chamber apparatus, with simultaneous vacuum flow of gasoline and of atmospheric air, is permanently established and must be retained. Adhering to this principle of construction as the basis of proportioning and of the first step in mixing, does not prevent the addition of other elements to correct the faults inherent in the simple combination. Mixture proportioning correctors in the form of compensators to reduce the natural tendency for gasoline to flow in excess at high rates of vacuum when the ratio is correct for low, are now available in considerable variety and some are fairly good, though even in the best there is considerable room for improvement. These compensators constitute the principal differences between modern carburetors.

It is in control of mixture quality in other respects than proportioning that carburetors now available are lacking; for example, to render the mixture quality independent of atmospheric changes, fuel supply, pressure fluctuations, and above all independent of their own cooling action. This self-cooling is due to vaporization of gasoline, the latent heat for which lowers the temperature of the mixture below that of the entering air. Heat must be supplied if liquids are to be vaporized, and no amount of human ingenuity can overcome this law of physics. If the latent heat of vaporization be supplied from waste heat sources for so much of the gasoline as can vaporize in its air supplied at atmospheric temperature, then the resulting mixture will have the same temperature as the atmosphere and there will be neither vapor condensation nor water freezing on the intakes. Such mixtures especially when the air is cool are not sufficiently dry and certainly are variably dry, dryness varying with atmospheric temperature. To produce even this much effect requires a considerable amount of heat from either hot jacket water or exhaust gases. To get this amount of heat into the entering air or the mixture it is necessary to observe the laws of heat transmission and provide sufficient heating surface of suitable form. To simply surround the body of the carburetor with a water jacket or to take the air from a short exhaust-pipe jacket, which are the only means now in general use, is entirely inadequate, as can be proved by simply taking the mixture temperature by a thermometer in the intake pipe or by observing the flow through experimental glass headers and branches. Of course such wall heaters will prevent any adhering frost, but they can not prevent its formation as free snow to be drawn into the cylinders. This problem of mixture making by carburetors is one of the most important of all the elements of the aero engine structure and the carburetor proper its most important apparatus, on which much work has been done, but more remains, especially of the adaptation order.

(In this connection the paper by Dr. Karl Buchner on carburetion, which is one of the best, is reproduced in full in the appendix.)

Distribution of the mixture from the carburetor to the cylinder inlet valves without change of quality in transit, and in such a way as to insure a supply of mixture of equal quality to each cylinder, is a problem of equal importance to that of correct mixture making and is intimately associated with it. If the carburetor should yield correctly proportioned mixed and completely dry mixtures, this distribution header problem disappears, and any form of branch pipe will serve the purpose in place of the long elaborately curved headers now in use. Such mixtures are too warm to develop the maximum possible mean effective pressure. To get the greatest power output per cubic foot of piston displacement per minute requires a temperature lower than corresponds to complete dryness, probably corresponding to just such quantity of moisture as can be evaporated during entrance through the inlet valve and, therefore. the aero engine header may be expected to carry some moisture.

Such mixtures have a tendency to separate the liquid, which resists division equally among the branches, and where vertical flow must take place there is a tendency for the liquid, which always flows along the walls to drop back by gravity, to accumulate, and then suddenly carry over as a wave, causing a miss, especially at low-engine capacity. To prevent lagging of liquid, vertical pipes must be made so small as to produce skin friction forces superior to gravity at the lowest flow rates. If this is done then, at high flow rates, a considerable drop in pressure with consequent loss of power will result, unless, as is often the case, the carburetor is located at the highest point and the liquid allowed to drain downhill with the mixture current in large pipes. On reaching a bend the liquid flowing along the side walls always collects on the inside as the air stream impinges on the outside, while at a Y or branch the liquid may choose almost any path and is quite beyond control, for wherever the mixture velocity is locally least then the liquid concentrates and this point is constantly changing. The best that can be done is to use long-radius bends and flow paths to each cylinder of approximately equal length and curvature, but this gives no assurance of equal distribution of liquid. The frequent use of two carburetors on six cylinders in line and eight cylinders V engines is evidence of an effort to reduce this trouble.

The only absolutely reliable way to avoid these special headers and the irregular engine action that results in two cylinders never doing quite the same work or remaining equally clean, is to completely dry the mixture by raising its temperature, accepting the higher temperature and lowered mean effective pressure in the interests of cleanly, steady, operation, securing shorter simplified headers and possibly making up lost output by a small increase in cylinder diameter or by raising the mixture pressure by blowers. There really seems to be considerable reason for the use of blower-supplied air for carburetors other than to compensate for loss of density when mixtures are warmed to dryness, which heating incidentally renders the engine more independent of variations of fuel quality than it now is. By suitable regulators the air blast can be controlled so as to give always the same absolute pressure at the carburetor intake, regardless of barometer or flight speed and direction. With such an

auxiliary blower and pressure regulator, the friction effect of intake ports and small-diameter low-lift valves, while remaining a direct engine resistance, will have no effect whatever on the weight of charge per stroke and the mean effective pressures. Other things being equal, an initial pressure in the cylinder of 16, as compared with 14 pounds per square inch absolute, an increase of 2 pounds should increase the mean effective pressure and power one-seventh, over 14 per cent, while adding only 2 per cent additional load (if the mean effective pressure were 100 pounds), a net power gain of over 12 per cent if the blower be efficient. The use of such blowers is not unknown in two-cycle engines, though four-cycle engines have not employed them as yet, and the N. E. C. (New Engine Co.) two-cycle engine is so equipped, the blower in this case taking the place of a piston as a precompressor to prepare the charge for entrance into the motor cylinder when the port uncovers.

All two-cycle engines and all rotating cylinder four-cycle engines with inlet valves in pistons have mixture quality and supply conditions somewhat different from those of the four-cycle fixed-cylinder engines, and among the latter the air-cooled differs somewhat from the water-cooled group. The cylinder heads of four-cycle air-cooled engines are normally hotter than those that are water cooled, so that the mixture entering will receive more heat and may, therefore, be more wet as supplied, provided distribution from the carbureter is not a disturbing element, as, for example, if each cylinder had its own separate carbureter. If cylinders are not too large and the air cooling is vigorous it is possible to get the walls of the air-cooled cylinder quite as cool as the water-cooled one but only with excessive power consumption for air circulation, the Renault, for example, taking 8 per cent of its output for only such cooling as is normally provided. Most of the rotating-cylinder four-cycle engines with inlet valves in the pistons, including the Gnome, for example, take their mixtures into the crank case at the shaft center. In this crank-case chamber, which is rapidly whirling, with pistons churning up and down at the same time, a most vigorous stirring and heating action takes place. It would be hard to conceive of a better mixture conditioning apparatus than this Gnome crank case, provided there were some means of control of the temperature of the mixture, which in this case undoubtedly gets too warm, though dryness and homogeneity are practically perfect. Finally, two-cycle engines take the mixture from the carbureter into an auxiliary chamber for precompression, located in the crank case as the most favorable arrangement, or in a trunk enlargement of the main piston and cylinder preferably, as, for example, in the Laviator engine. While, of course, this precompression mixture has the evil effect of imposing negative work, equivalent to engine friction, it is highly beneficial as to mixture quality when the precompression chamber is so located, as is usually the case, as to get and stay warm, because in this case the chamber is at once a mixture stirrer and heating dryer, heating partly by wall contact and partly by compression.

Mixture treatment in the cylinder after it has been made and delivered to the intake port, begins with actual entrance and proceeds along different lines in the two and four cycle engine, in some respects. Nearly all aero engines are four-cycle engines, and these take the mixture in through a suction valve under the influence of

the lowered cylinder pressure maintained by the piston outstroke. This admission should be accomplished with the least possible loss of pressure and rise of temperature. Loss of pressure imposes direct negative fluid friction work, the extent of which is measured by the velocity of flow through the valve, and the shape of the opening, but even with small valves and badly shaped openings or ports, this loss may be, but not often is, very serious. Two pounds per square inch would be large and with mean pressures approaching 100 pounds it would be equivalent to a little over 2 per cent. However small it may be, it can be controlled by valve and port dimensions and these, because of the high speed of aero engines, must be given far more attention than in any other class. It is the terminal pressure at the end of the suction that is one of the determining factors in the weight of the charge, each pound per square inch accounting for about 7 per cent loss of power. Since inertia of the incoming stream tends to build up the terminal pressure over the mean suction pressure, if valve closure is delayed the right amount, the value is so great that care must be exercised to secure it, and Winkler recommends a closure 40° after dead center. This delayed inlet valve closure can be secured only by mechanical inlet valves which also give best control over the mean suction resistance, so that under no consideration should automatic inlet valves be employed, as they have been, to save valve gear weight, because more power is lost than would compensate for this weight. Charge density at the end of suction is just as much a matter of temperature as of pressure, a rise of about 500° F. on entrance accounting of itself for about a 50 per cent reduction of charge weight and hence of power output, or approximately 1 per cent for every 10° rise, with the probability that the rise averages in well-cooled engines somewhere about 200°, or 20 per cent, and in the less well-cooled ones over 300°, or 30 per cent, in general round numbers.

Reduction of suction heating is partly a question of arrangement and partly of wall cooling but to some extent depends on the temperature of the hot gases left in the clearance after the previous explosion. As to arrangement, head valves discharging mixture directly into the cylinder seem to be more rational than side-pocket valves, though no data are available to prove that the former results in less suction heating than the latter. It also seems likely that air-cooled heads and valve chambers unless vigorously air blasted and of small chamber should heat the mixture more than water-cooled ones, but no one has ever determined how small a diameter can be equally well cooled by air and water nor how much air is needed. Nor can it be said how much of the total suction heating is due to exhaust gas mixture in the clearance with the fresh incoming charge. It is interesting to note that the air-cooled radial fixed cylinder Anzani gave in the tests 99½ pounds square inch effective pressure referred to brake horsepower, as much as most of the water-cooled engines.

Not only is it important that the charge in the cylinder be as cool as possible for the maximum charge density required for high mean pressures, consistent, of course, with complete vaporization, for which 120° F. is enough with gasoline if the mixture is well stirred, but it is perhaps even more important as the controlling factor in the permissible compression. This degree of compression of the charge before

ignition is the prime variable in fuel consumption per horsepower hour and thermal efficiency, as has been demonstrated conclusively both by thermodynamic analysis and experimental data on all classes of internal-combustion engines. The highest compression possible must be obtained at all costs, and since it is the ignition temperature of the mixture that imposes a limit the objective of the engine designer must be to so treat the mixture as to get the maximum compression volume ratio and final pressure before the mixture being compressed reaches the ignition temperature which is a physical constant of the mixture, never accurately determined but probably very close to 935° F. This compression for the best water-cooled engine has been found to be about 5 to 1 volumes and less for cylinder not so well cooled. Of course, self-ignition before compression is complete will occur if any metal part, such as the exhaust valve or piston head, or a carbon deposit, is overheated, because this will produce a local overheating of the charge in contact with the hot spot before the whole mass has reached the ignition temperature. Prevention of this is a matter of engine cooling and of the internal cleanliness that comes with proper lubrication and carburetion. Assuming such to be properly cared for, the compression permissible with gasoline mixtures is fixed by the initial temperature of the charge. The final temperature varies with the initial in a geometric ratio, as is indicated by the standard equation for adiabatic compression, so a few degrees rise initially results in several times as great a terminal rise.

Charge weight per cubic foot of suction must be a maximum, and so also must the compression, if the mean effective pressure and thermal efficiency are to have the highest possible value, as they should in aero engines. All efforts in this direction may be entirely defeated, however, if there is any material leakage of the charge during compression through valve seats or past the piston. It is of no value to secure maximum charge weights during suction if appreciable amounts are afterwards lost before the charge has a chance to do any work. Tightness of piston depends on the piston rings, on the oil film between piston and cylinder, and on the maintenance of shape of cylinder and piston, neither of which may warp in any direction. Valve leakage likewise is minimized by providing nonwarping valve disks and seats with strong spring loads to keep the valve tightly against its seat during the first period of compression; at other times the gas pressure itself will suffice. These are questions of form and materials and will be taken up later, but they are mentioned here because a failure means defeat of the results of an otherwise well-executed suction process.

Four-cycle engines, after the suction periods, have their charges directly in the cylinder ready for compression and subsequent ignition. Two-cycle engines must put the charge through the preliminary compression process in a precompression chamber where the mean pressure of precompression must be added to that of suction, the sum of the two subtracted from the mean effective pressure of the compression and expansion strokes to get the net available. Therefore, assuming equal performance of the compression and expansion strokes, the two-cycle engine is charged with more negative work than the four-cycle by the amount of the precompression stroke, assuming equal negative work of suction in each. Suction heating effects on the two-cycle are bound to be less than in the four, because the precompression cylinder is sure to be cooler than the working cylinder

into which the four-cycle charge enters directly, and so also is clearance gas with which the fresh charge mixes, as in the two-cycle case; this is reexpanded fresh charge remaining after discharge, while in the four-cycle it is hot burnt gases. All this two-cycle pump chamber charge will not enter the working cylinder nor remain there, for some will remain in the precompression chamber by reexpansion or failure of the pressure to drop during the open-port charging period to atmosphere. Some will escape through the exhaust port with the exhaust gases during the end of the transfer period when both transfer and exhaust are open, regardless of piston baffles of or special relative positions of inlet and exhaust ports designed for the purpose. During transfer the fresh charge bodily displaces the hot burnt gas that fills the motor cylinder and its clearance, and it is inconceivable that a considerable amount of mingling should not occur with corresponding heating and expansion effects. These mixture-heating effects are added to those of wall-contact heating, which walls in the two-cycle engines are always much hotter than in the four. The net effect is inevitably a discharge of some of the fresh charge with the burnt gases unless special arrangements are made to prevent this, and then each of these introduces its own evil.

Two methods of preventing this fresh charge heating on transfer in two-cycle engines and consequent loss of charge are in use, one is to intentionally reduce the charge transferred to so small a quantity as will not escape, and the other to expel burnt gases by a blast of fresh air, and then to expel this scavenging air which, of course, is cooler than the burnt gas, by the fresh charge. The former means intentionally reduced charge while the latter more than doubles the negative work of precompression which in effect is equivalent. Some part of the compression stroke in any two-cycle engine, so much as is required to cover the exhaust port, must result in further expulsion of charge. Naturally as in four-cycle engines, the charge weight can be built up in two-cycle engines to any value, by sufficient precompression, but to accomplish this the charge must continue to enter after the exhaust port is closed, which requires an admission or transfer valve mechanically operated and suitably timed, an extra complication. This is not common practice and no data are available on it, so for the present it must be regarded as merely an interesting possibility.

In the two cycle engines the net effect of all heat exchanges and pressure changes, incident to charging the main cylinder, is undoubtedly a lower mean effective pressure and thermal efficiency than in four-cycle engines, and for equally good design and construction in each class the two cycle is unable to carry compressions as high as the four, proving higher temperatures before compression. Any engine taking its charge into the crank case, as do most of the rotating cylinder four-cycle machines, or into a chamber connecting with the main piston, as the two-cycle Laviator, is subject to mixture quality impairment and equivalent charge loss, whenever the main piston leaks under its high explosion pressures, by the displacement of the fresh by the burnt gases.

While dealing with charge weights and volumetric efficiency of cylinders, the exhaust stroke of the four-cycle cylinder and the reexpansion stroke of the two-cycle precompression chamber must be considered as controlling by their terminal conditions of pressure

the point of the return or suction stroke at which charging will actually begin. No flow can be started from the intake header until the clyinder pressure is lower. At the end of the four-cycle exhaust stroke the cylinder pressure is higher than atmosphere, and still higher than the mixture-header pressure by the amount of the suction-header vacuum. Suction can not begin until the cylinder clearance volume of gases has expanded enough to lower the cylinder pressure (terminal exhaust value) to below that of the mixture header. An appreciable part of the suction stroke is therefore useless for actual charging, the loss increasing with higher terminal exhaust pressures and lower suction-header pressures. A similar condition exists in the two-cycle precompression chamber; for there the pressure at the time the transfer to the working cylinder is complete must be something higher than atmosphere, and the higher the speed the more excess there must be, because of the limited time for pressure equalization. This mixture must expand not only to atmosphere, but as much below as the suction header or carbureter vacuum, even with a mechanically operated valve, and still more with the more common spring closed automatic check valve, by the amount of spring tension and valve inertia, before real suction can begin. The clearance in such precompression chambers is large, to limit the maximum precompression pressure to something less than 10 pounds per square inch, and, therefore, the reexpansion line will be very flat, cutting off a considerable part of the stroke as useless before the pressure has dropped sufficiently for suction to start. Many times the loss occurs here, as in four-cycle cylinders with their smaller clearances and steeper reexpansion lines, even with equal pressures at the start.

No separate data are obtainable for aero engines on any one of these quantities concerned with charge weight and the corresponding pressure and temperature changes, nor is there any indication that such information has even been sought. Even the over-all effects, as measured by volumetric efficiency, have apparently not been investigated, though all that is required is a measurement of air and gasoline or exhaust gas and a comparison with the piston displacement, the ratio of volumes constituting the true volumetric efficiency. Other things being equal, the horsepower per cubic foot of displacement per minute should be directly proportional to this volumetric efficiency, so it is a little surprising that the aero interests, which must have the most powerful engine per pound of metal, should have neglected to separately study each of the prime variables. As already noted, more designers seem to have been concerned with reduction of metal volume than with process perfection, though without proper execution of basic processes metal reduction may not only fail to give a light engine, but may even defeat the ultimate object by making the engine as structurally weak as it is weak in mean effective pressure or thermal efficiency. It must not be understood that no good performance results based on proper execution of the processes have been obtained; in fact, there are some most remarkable successes; but, on the other hand, these stand out so strongly as to prove that the procedure that has resulted so successfully is not the rule in the art, and may even in the case of the successful engine be as much a matter of good luck as patient, systematic investigation.

Assuming a good charge weight in the cylinder, or a high volumetric efficiency, the cylinder has at least the capacity for a high mean effective pressure and thermal efficiency, provided the subsequent treatment is proper. This treatment consists in compression with ignition before it is completed; combustion as rapid as possible consistent with absence of shocks; and expansion ending before the end of the stroke, by early opening of the four-cycle engine exhaust valve to drop the pressure to as near atmosphere as possible, at the end, and by uncovering the exhaust port of the two-cycle engine to get the same drop low enough before the end of stroke to allow the fresh charge to enter. It can be shown that both the mean effective pressure and the thermal efficiency will be highest for a given cylinder charge when the combustion starts as late as possible on the compression stroke and is completed as soon as possible on expansion stroke, or, referring to the shape of the indicator card, when the explosive combustion line is practically vertical, leaning, if at all, toward the expansion line than oppositely. Such a condition of affairs results in the Otto gas cycle, the efficiency of which is a function of compression only and the mean effective pressure of which is a function, partly of the compression, but also partly of the height of the vertical explosion line, which in turn depends on the weight of the charge or the volumetric efficiency. Should the combustion line be not of this shape, results are bound to be inferior, as can be demonstrated thermodynamically, and yet the maintenance of such explosion lines in service operation so fundamentally related to results, is now as much a matter of hand adjustment as of design. This is a strong reason for caution in applying special test results obtained by skilled enginemen, to conclusions of aero engine possibilities in actual service, where engine skill is likely to be less than in the shop or laboratory and where, even if it were not, the problems of flight control are so absorbing as to minimize the attention that can be given to engine adjustment. Recognition of this condition also suggests the great desirability of exerting sufficient effort in design, to reduce to a minimum or eliminate entirely the dependence of the operating result on such adjustments as affect the shape and position of the combustion line. Such explosion lines as are desired and needed for maximum power and thermal efficiency will result, if the combustion period is confined to within a sufficiently small crank angle at the inner dead center when the piston is substantially at rest, and it is common to take this angle as about 30° half before and after dead center. At a rotative speed of 1,200 revolutions per minute about the minimum for the good aero engines, or 20 revolutions per second, each revolution is completed in 0.05 second, and an angle of 30° being one-twelfth of a revolution combustion will be completed in about 0.004 second. The higher speed engines of 2,400 revolutions per minute must accomplish the result in half the time or 0.002 second. In this short time the mixture must be ignited, and the flame communicated from particle to particle, till all the mixture has been burned, even the part most distant from the ignitor. Assuming a uniform linear rate of flame propagation or flame speed and a 6-inch diameter cylinder about as large a one as any aero engine carries, the flame must travel half a foot in 0.004 to 0.002 second, which requires a linear velocity

of 500 to 1,000 feet per second, or 30,000 to 60,000 feet per minute if a single igniter is used on one side.

While no direct data on the possibility of attaining such rates by normal propagation are available it is likely that from interpretation of indirect data, they are probably not reached, so the rates are abnormal or maximum pressures not attained. At any rate conditions that could in any way improve this situation must be grasped and utilized. The first of these is concerned with mixture proportions which exert so strong an influence on the rate of propagation in explosive combustion. This is another argument for perfection of carburetion, and for the continuous maintenance of the exact proportions found best, because even a slight change of proportions, such as would never be noticed in an automobile, may exert a powerful influence under the steady high speeds of the aero engine. Next in order comes the flame path itself which if cut in half reduces the necessary combustion rate to half and this is partly a question of shape of combustion chamber and partly one of number and location of igniter plugs. It certainly should take less time to inflame the charge in an engine with valves in the head than in a tee-head form, for example, if each had one plug, so the former shape is preferable on this score. It would seem as if one plug located in the center of the head would ignite the whole charge in the time required for the flame to travel a distance equal to the radius and, therefore, that such a location whould halve the time required by one plug located at the side, yet no such degree of difference has been established. Moreover, it would seem that two plugs simultaneously sparking, and located at opposite ends of one diameter would require more time to accomplish ignition than one in the center as each separate flame would have to travel more than a radius to burn all the mixture, and yet two such plugs seem to give a quicker combustion than the one in the center, instead of slower. This question of combustion rate versus spark plug location and number is still pretty well open, though clearly of considerable importance in securing proper combustion lines for most effective working. Reliability should also be served as there is a better chance of avoiding failure with two independent magnetos and two sets of spark plugs than one, and this much has been established as good practice, but accurate simultaneous sparking of both plugs is absolutely necessary.

There are two considerations that bear on the question, both of which require definite investigation. In the first place it is the volumetric rate of combustion that is of primary importance, not the linear rate. It is clear that a greater volume of mixture will be burnt with a fixed linear rate, if the ignition is at the center of a complete sphere of flame as the sphere has a greater volume for its radius than any other geometric body. This would seem to favor central ignition, but as the normal aero engine combustion chamber with head valves is a short cylinder in which the axis is short compared with the diameter, ignition at the center will burn in the first half of the total time a mixture volume proportional to the area of a circle of half the bore, while during the second half the circular ring between this circle and the cylinder wall will burn and this ring has three times the area and volume of the center cylinder. Therefore, with central ignition, the volumetric rate is low at first, and high

at the end, averaging three to one in the second as compared to the first half, and it is the second half that is most important because here expansion is beginning and tending to lower pressures which it is the function of combustion to raise. If the situation be reversed so that the higher rates occur in the early part of the period available, then there will be less to burn after expansion has started and this will be accomplished by two plugs. The second consideration is that of non-uniform rate of propagation or accelerated combustion, and recognizes that mixtures which are agitated, burn much faster than those that are quiet. The advancing combustion wave started at any ignition point agitates the mixture beyond, somewhat like a compression wave, and two ignitors may be expected to increase this agitation and so accelerate combustion, compared with single point.

Whatever the rate of combustion, it is necessary to start combustion before the end of compression, and the slower the combustion rate, or the higher the piston speed, the more advance must be allowed. This advance, needed to limit the combustion completion time must be as small as possible because pressure rise during compression is just as detrimental as excessive friction, and is accepted at all only as the lesser of two evils. It would seem as if, with sufficiently high volumetric rates of combustion, and a sufficiently large number of ignition points, spark advance would be minimized. Manual advance might even be eliminated entirely as an operator's adjustment, if the magnetos and distributors used had proper electrical characteristics with speed increases to give earlier sparks passage at higher speed. With widely varying throttle openings and engine speeds, such as are typical of auto engines, chances of success are more remote than with aero engines where speed and throttle positions are changed so seldom.

While it is possible to experimentally determine the degree to which each process step important to the power weight ratio has been executed in an aero engine, and to measure the precise amount of disturbing effect of each interfering influence to be encountered in practice and, therefore, experimentally study processes with reference to reliability and adaptability as well, no such work appears to have been undertaken or, if it has, the results have not been recorded. All that has been published with respect to the judging of process fulfillment has been concerned with a few simple over-all measurements of horsepower, speed, and fuel consumption from which some conclusions are derivable, but not of such significant value to designers and operators of engines as would be the case with true investigation work of the analytical character that accounts separately for each factor that enters into the result. As has already been pointed out, these results are subject to some interpretation by comparison, one with the other, and each with thermodynamic standards. All the facts necessary for the latter are not available, and must be assumed in part, so the conclusions will be correspondingly approximate and subject to caution in use.

From the measured brake horsepower and speed, the speed can be eliminated by division and a quantity obtained which measures the effectiveness with which those processes that are concerned with output have been executed, and this is the mean effective pressure referred to brake horsepower. This quantity, of course, includes all

negative work of gas friction through carburetor header ports, valves, and exhaust muffler, all mechanical friction, all fan, pump, and magneto work; all negative work of precompression in two-cycle engines and the windage of rotating cylinder engines. For the most satisfactory conclusions these included items of loss should be separately determined and certainly the motor cylinder work done behind its piston should be isolated from the rest, but up to the present the only separate factor thus embraced is the windage of the rotating cylinder engines in the German tests. Comparison of these over-all competition test results giving the mean effective pressure referred to brake horsepower with each other is possible from Table IV.

TABLE IV.—*Mean effective pressures referred to brake horsepower versus engine classes.*

Class No.													
I.		II.				III.		IV.					
Cylinder-crank arrangement.													
Fixed in line.		Fixed V, 2 cylinders per crank.				Rotating.		Fixed star.				Miscellaneous.	
Cooling.													
Water.		Air.		Water.		Air.		Air.		Water.		Air.	
Engine or maker.													
Benz.		De Dion-Bouton.		Curtiss.		B. M. & F. W.		Anzani.		Laviator, 2 cycle.		Ashmusen.	
M.E.P.	Authority.	M.E.P.	Authority.	M.E.P.	Authority.	M.E.P.	Authority.	M.E.P.	Authority.	M.E.P.	Authority.	M.E.P.	Authority.
106.9	Bendman.....	67.3	"Flight".....	107.7 111.7 104.7	Maker.........	66.6	B............	76.5 78.5 76.9	Maker..........	65	"Flight"......	77.5	Maker.
Daimler.		Renault.		Sturtevant.		Gyro.		Anzani.		Salmson.			
114.4	B............	64.1 60.2	"Flight".....	100	Maker.........	76.9	B............	83.2 80.1 86.8	Maker..........	83.5 92.8	"Flight"......	....	
Daimler.		Wolseley water-cooled exhaust box.		Sunbeam.		Gnome.		Edelweiss.					
108.5	B............	79	"Eng'g"......	127	Maker.........	75.0	B............	97	"Flight"......	....	....	....	

Daimler.				Rausenberger.		Gnome.		Laviator, 2 cycle.					
102.0	B.........	......	....	103	Marker......	71.3	B..........	57.2	"Flight".....	......	....	......	
Daimler.				Clerget.		German Gnome.		1911 Anzani.					
107.1	B.........	......	....	101.5	"Flight".....	67.9 / 67.2	Maker......	90.56	Lumet......	......	....	......	
Daimler.				Laviator.		German Gnome.		1911 Nieuport.					
107.0	B.........	......	....	106 / 92.5	"Flight".....	78.7 / 65.2	Maker......	86.76	Lumet......	......	....	......	
Daimler.				Panhard Levassor.		Le Rhone.							
104.8	B.........	......	....	82	"Flight".....	85.6 / 80.2	Maker......	......	....	......	....	......	
Daimler.				Wolseley.		Clerget.							
98.0	B.........	......	....	77	"Eng'g".....	57.6 / 72.8	"Flight".....	......	....	......	....	......	
N. A. G.													
106.0	B.........	......	....	......	....	......	....	......	....	......	....	......	
N. A. G.													
94.9	B.........	......	....	......	....	......	....	......	....	......	....	......	

TABLE IV.—*Mean effective pressures referred to brake horsepower versus engine classes*—Continued.

Class No.													
I.		II.				III.		IV.					
Cylinder-crank arrangement.													
Fixed in line.		Fixed V, 2 cylinders per crank.				Rotating.		Fixed star.				Miscellaneous.	
Cooling.													
Water.		Air.		Water.		Air.		Air.		Water.		Air.	
Engine or maker.													
Argus.													
M.E.P.	Authority.	M.E.P.	Authority.	M.E.P.	Authority.	M.E.P.	Authority.	M.E.P.	Authority.	M.E.P.	Authority.	M.E.P.	Authority.
106.5	B												
Argus.													
107.5	B												
Argus.													
101.1	B												

Mulag.													
101.3	B												
Schröter.													
79.2	B												
Hall-Scott.													
92.75	Maker												
Austro-Daimler.													
93	Austrian Army official.												
Wright.													
83.7	Maker												
Sturtevant.													
103.8	Maker												
Chenu.													
96 .04 110 102	"Flight"												

TABLE IV.—*Mean effective pressures referred to brake horsepower versus engine classes*—Continued.

Class No.													
I.		II.				III.		IV.					
Cylinder-crank arrangement.													
Fixed in line.		Fixed V, 2 cylinders per crank.				Rotating.		Fixed star.				Miscellaneous.	
Cooling.													
Water.		Air.		Water.		Air.		Air.		Water.		Air.	
Engine or maker.													
Clerget.													
M.E.P.	Authority.	M.E.P.	Authority.	M.E.P.	Authority.	M.E.P.	Authority.	M.E.P.	Authority.	M.E.P.	Authority.	M.E.P.	Authority.
98.3 101.5	"Flight"												
Green.													
74	McCoull												
1911 Labor-aviation.													
102.4	Lumet												

1911 Aviatic.													
118	Lumet												
1911 Chenu.													
96.33	Lumet												

Values of mean effective pressure exceeding 114 pounds per square inch, referred to brake horsepower, reported for one engine, and in many instances in excess of 100 pounds per square inch for water-cooled fixed-cylinder engines, warrant the conclusion that little betterment is possible in view of the prevailing lower figures in engines of other classes. These attained values are truly remarkable and can hardly be exceeded unless the initial pressures are raised above atmosphere by blowers. That some engines do not attain these values is proof of their inferiority of design, but there is some question as to capacity for maintenance of the high value after long periods that can be settled only after very long trial runs. The contest figures are reliable and acceptable for the conditions imposed, and if such values can be maintained in flight, little more can be expected. Such a high value as 127 pounds reported by one maker can hardly be credited, nor can so low a value of 74 pounds be regarded as good enough to be acceptable. Air-cooled cylinder values are consistently lower even for fixed cylinders and much more so for rotating cylinders, which indicates a fundamental inferiority.

There is some question of the validity of a comparison of mean effective pressures for different engines at unequal speeds, especially as rotating cylinder engines are never run over 1,500 revolutions per minute while fixed cylinder engines are operated over 2,000 revolutions per minute. To eliminate such an objection and at the same time permit of a judgment of the best speed at which to run an engine of given design, the horsepower-speed curve should be determined, or its equivalent curve of mean torque speed, or of mean effective pressure referred to speed. It is evident that, if with an increase of speed the mean effective pressure remains constant, then the horsepower will be proportional to speed, and the best speed to use for aero engines will be the highest at which the inertia or centrifugal forces are not excessive, assuming proper bearing conditions to be provided. This best maximum speed for fixed cylinder engines is undoubtedly the speed at which the inertia force of the reciprocating parts at the beginning of the outstroke is equal to the normal maximum gas-pressure force acting on the piston. For these conditions the force transmitted to the crank pin at the moment of explosion will be zero, gradually rising through the stroke and will be maintained high until near the end of the outstroke during the last half of which the increasing inertia forces are additive to the lessening gas pressure forces. During the idle stroke of suction the inertia force acting alone imposes just the same crank-pin forces as would the explosion when starting. Any less inertia while reducing the transmitted crank-pin forces for idle strokes increases them at the beginning of the working stroke. As the normal or most used speed is less than the maximum and the maximum gas pressures likewise, this normal condition and not that of maximum should be made the basis of selection of operating speed for minimum weight of engine, coupled with general serviceability. The speed at which normal maximum gas pressures will be balanced against reciprocating inertia, which is a function of the square of the speed and of the weight of parts directly, will, of course, depend on these weights. Heavy reciprocating parts may be best operated at lower speed than light reciprocating parts which include piston, wrist pin, and part of the connecting rod.

For a water-cooled engine of the automobile type Winkler gives 350 pounds per square inch as the maximum explosion pressure. Accordingly from the equation, reciprocating inertia pounds per square inch of piston $= 0.00034 \frac{W}{a} N^2r$, and taking $\frac{W}{a} = 0.5$, calculated from the weight distribution figures given by Winkler, the speed at which this would become equal to 350 pounds per square inch is 2,640 revolutions per minute. (NOTE.— $\frac{W}{a}$ = pounds reciprocating weight per square inch piston, N = revolution per minute, r = radius of crank in feet.) The rotating cylinder engine introduces a different condition, for here the reciprocating parts always exert a centrifugal force varying from a maximum at out center to a minimum at inner center and such as will keep the connecting rods always in tension if speed and reciprocating weights are large enough to develop centrifugal forces higher than the gas pressure, the maximum for which is found at 250 pounds per square inch normal.

From this standpoint the operating speed or high limit is fixed by the weight of reciprocating parts, and the normal maximum gas pressures, and this is the controlling factor so long as mean effective pressures do not fall off materially with speed. Examination of any horsepower-speed curve will show it to have a straight line form up to some critical value which is easily determined by test, though no authentic curves are available for aero engines. Of course, this critical speed must be beyond the operating range and is a second high limit to be considered in conjunction with that imposed by inertia. The best procedure is undoubtedly the selection of such proportion of gas passages, carburetor, and ignition conditions on the one hand, and reciprocating parts weights on the other, as will bring the critical speed equal to the inertia speed limit. Curvature of the horsepower-speed curve is due partly to increased losses of charge at the higher speeds, and partly to insufficient rate of combustion. Which of these two is in any instance the controlling factor must be discovered before any plan of improvement can be undertaken and this is most directly done by plotting the volumetric efficiency-speed curve beside the horsepower-speed curve. If the latter departs from the straight line before the former, it is clearly not due to insufficient charge. In such a case enlargement of valves or ports, or reduction of carburetor vacuum will not improve matters at all, as it is a low rate of combustion that is responsible for the result, to cure which attention must be devoted to mixture quality and ignition.

Fuel consumption per horsepower hour, or the equivalent thermal efficiency, is also an indication of the overall effectiveness of the process execution, and comparison of engines on this basis can be made from the data of Table V, selected from the test reports. These would tell more if divisible into the factors as indicated in considering the mean effective pressure.

TABLE V.—*Fuel consumption (pounds per brake horsepower-hour) and thermal efficiency versus engine classes*—Continued.

Class No.									
I.		II.		III.		IV.			
Cylinder-crank arrangement.									
Fixed in line, 1 cylinder per crank.		Fixed V, 2 cylinder per crank.		Rotating.		Fixed star.			
Cooling.									
Water.		Water.		Air.		Air.		Water.	
Engine or maker.									
Argus.									
Fuel.	Efficiency.	Fuel.	Efficiency.	Fuel.	Efficiency.	Fuel.	Efficiency.	Fuel.	Efficiency.
0.534	0.26	....	....	....	....	....	....	....	....
B.									
Argus.									
0.588	0.23	....	....	....	....	....	....	....	....
B.									
Argus.									
0.586	0.23	....	....	....	....	....	....	....	....
B.									
Mulag.									
0.528	0.26	....	....	....	....	....	....	....	....
B.									
Schröter.									
0.621	0.22	....	....	....	....	....	....	....	....
B.									

TABLE V.—*Fuel consumption (pounds per brake horsepower-hour) and thermal efficiency versus engine classes*—Continued.

Class No.									
I.		II.		III.		IV.			
Cylinder-crank arrangement.									
Fixed in line, 1 cylinder per crank.		Fixed V, 2 cylinder per crank.		Rotating.		Fixed star.			
Cooling.									
Water.		Water.		Air.		Air.		Water.	
Engine or maker.									
Hall-Scott.									
Fuel.	Efficiency.	Fuel.	Efficiency.	Fuel.	Efficiency.	Fuel.	Efficiency.	Fuel.	Efficiency.
0.6	0.21	....	....	....	....	....	....	....	....
Maker.									
Austro-Daimler.									
0.52	0.26	....	....	....	....	....	....	....	....
Government Acceptance Test.									
1911 Labor-Aviation.									
0.617	0.22	....	....	....	....	....	....	....	....
Lumet.									
1911 Aviatic.									
0.595	0.23	....	....	....	....	....	....	....	....
Lumet.									

NOTE.—For Continental engines a calorific value of 18,900 British thermal units per pound has been assumed, for American and British engines 20,400 British thermal units per pound.

Fuel consumption of less than half a pound per brake horsepower-hour, reported for fixed water-cooled cylinders on reliable authority, with corresponding thermal efficiencies approaching 30 per cent, are nothing short of wonderful for such high-speed engines, and judging

by the performance of other classes of engines and by the thermodynamics of limiting possibilities, little more can be expected. What must be sought for here is, therefore, not an improvement of the best, but a general raising of the poorer ones to level of the best, and the maintenance of the high test value in actual-service flight. In this prime factor, as in that of mean effective pressure, the fixed water-cooled cylinder has a demonstrated superiority, while the least favorable is the rotating air-cooled. The difference between the best and worst is very large indeed.

Comparison of engine results with each other, especially when it is not possible to divide overall results into contributing factors, can give no information as to how far it may be possible to further improve engines. It merely indicates which is the better, and may throw some light on type availability, as, for example, the fuel consumption of two-cycle engines must always be greater than four-cycle, if each is equally well designed; or again, air-cooled engines may or may not have as high a mean effective pressure as water-cooled.

Thermodynamic standards of comparison do indicate goodness more absolutely, and these are now in general use in engineering practice. Accounting for and eliminating operative conditions, such absolute standards illuminate the goodness of the machine with reference to the execution of its basic process. Such, for example, is the case with steam turbines, the performance of which is compared with that of the Rankine cycle as a standard, for equal initial and terminal conditions of pressure, temperature, and steam quality. It is also the case with internal-combustion engines of the classes that have really been subjected to any reasonable degree of investigation which are judged by the Otto and Diesel gas cycles. But the aero engine has not as yet been so studied. According to this method equations are derived from a study of the ideal Otto gas cycle for thermal efficiency and mean effective pressure. Thermal efficiency, for example, referred to indicated horsepower is found to be a function of the amount of compression only, and given by the following equation, in which the subscript (b) refers to the condition after, and (a) to that before, compression:

$$E=1-\left(\frac{V_b}{V_a}\right)^{\gamma-1}=1-\left(\frac{P_a}{P_b}\right)^{\frac{\gamma-1}{\gamma}}=1-\frac{T_a}{T_b}$$

Comparing this with the thermal efficiency of an engine of known compression results in an efficiency ratio, and in Table VI are given some values for aero engines, computed with what data are available and certain assumptions noted. As the fuel consumption per brake horsepower-hour is the only experimental quantity beside the compression, the factor includes all losses, both mechanical and thermal, which former should really be separated out.

Similarly, mean effective pressure can be shown thermodynamically to be not only a function of compression, as is efficiency, but also of the calorific value of the mixture, the negative work and suction heating or volumetric efficiency. As these effects are not separately known, and as all aero engines work on gasoline, although benzol is also used in Germany, and are capable of making and using the same calorific power mixtures measured at 32°, and one atmosphere, this factor

disappears as a variable, and becomes a constant 103 British thermal units. The equation then takes the following form:

$$(m.\,e.\,p.) = 5.4 \times 103 \times \left[1 - \left(\frac{P_a}{P_b}\right)^{\frac{\gamma-1}{\gamma}}\right] - 556.2 \times E$$

Comparison of this computed result with that measured by test gives the diagram factors of Table VI, including all losses due to every cause. Comparison of the diagram factor with the efficiency factor for each engine indicates whether or not the interferences affecting one are greater than those that affect the other. For example, two engines might have identical efficiency factors and yet one may heat the charge much more than the other with a lower volumetric efficiency. This one will have a very much lower diagram factor than the other, or otherwise the ratio of efficiency factor to diagram factor will be different, and such is the case in general, comparing air-cooled with water-cooled engines, especially if the former are of the rotating cylinder heated crank case sort.

TABLE VI.—*Diagram factors and efficiency ratios.*

Class No.											
I.		II.				III.		IV.			
Cylinder crank arrangement.											
Fixed in line of 1 cylinder.		Fixed V?, 2-cylinder crank.				Rotating.		Fixed star.			
Cooling.											
Water.		Air.		Water.		Air.		Air.		Water.	
Engine or maker.											
Benz.						B. M. & F. W.		Nieuport.		Salmson.	
P.	*E.*	*P.*	*E.*	*P.*	*E.*	*P.*	*E.*	*P.*	*E.*	*P.*	*E.*
Diag. fact.	Efficiency ratio.	Diag. fact.	Efficiency ratio.	Diag. fact.	Efficiency ratio.	Diag. fact.	Efficiency ratio.	Diag. fact.	Efficiency ratio.	Diag. fact.	Efficiency ratio.
106.9 .353	0.29 .630	....	....	....	....	66.6 .222	0.16 .348	....	0.17 .370	78.2 .260	0.224 .487
Daimler.						Gyro.		1911 Anzani.			
103.5 102.0 .345 .340	0.27 .28 .587 .608	....	....	....	....	76.9 .256	0.17 .370	79.6 .332	0.20	....	....
Daimler.						1911 Gnome.					
107.1 107.1 .357 .357	0.27 .26 .587 .565	....	....	....	....	66.9 65.4 .223 .215	0.17 .370	....	....	....	....

TABLE VI.—*Diagram factors and efficiency ratios*—Continued.

Class No.											
I.		II.				III.		IV.			
Cylinder crank arrangement.											
Fixed in line of 1 cylinder.		Fixed V?, 2-cylinder crank.				Rotating.		Fixed star.			
Cooling.											
Water.		Air.		Water.		Air.		Air.		Water.	
Engine or maker.											
N. A. G.											
P.	*E.*	*P.*	*E.*	*P.*	*E.*	*P.*	*E.*	*P.*	*E.*	*P.*	*E.*
Diag. fact.	Efficiency ratio.	Diag. fact.	Efficiency ratio.	Diag. fact.	Efficiency ratio.	Diag. fact	Efficiency ratio.	Diag. fact.	Efficiency ratio.	Diag. fact.	Efficiency ratio.
101.0	0.28										
94.0	.26										
.337	.608										
.316	.565										
Angus.											
106.5	0.26										
107.0	.23										
.355	.565										
.337	.500										
Austro Daimler.											
94.0	0.26										
.31	.565										
Cheno.											
103.6	0.229										
106.5	.253										
Wright.											
80.2	0.182										
.267	.413										
Green.											
77.0	5.23										
.258	.504										

NOTE.—*E.* is thermal efficiency referred to brake horsepower and *P.* is mean effective pressure pounds per square inch referred to brake horsepower.

On account of lack of sufficient data for individual engines, a compression ratio of *1:4.5* has been assumed for all engines, equivalent to an air card efficiency of *45.0* per cent and theoretical *M.E.P.*=*300.*

These figures, which should throw so much light on performance, are, as a matter of fact, of but little value because of the absence of accurate data, especially on compression and engine friction, both mechanical and fluid. They are, however, given to illustrate the method of judging by thermodynamic standards rather than by simple comparison of engines one with the other, in the hope that in future tests such data will be obtained as to make possible the determination of both diagram factors and thermal efficiency ratios.

Continuity of the operation of mixture treatment in the cylinder is dependent on the maintenance of a steady state as to temperature of the metal parts, and this is possible only by a cooling system of considerable complexity from the thermal standpoint, however simple the apparatus may seem, superficially examined. Cooling for the maintenance of a steady state of temperature in the metal parts is not of itself sufficient, as the parts must be held to a low limit of temperature, which requires a definite heat conducting and dissipating capacity in proportion to the heat receiving capacity of the part. This limit of allowable temperature is imposed not only by the requirements of the charging and compression functions but is necessary for other reasons. If metal parts become too hot oxidation sets in, stiffness is reduced, and deformation, both the temporary sort resulting from expansion and the permanent sort due to molecular rearrangements, becomes troublesome. Cylinder lubrication is also dependent on the temperature of the metal surfaces, of piston barrel exterior and cylinder interior, which, if too high, prevents any oil remaining without destructive distillation or carbonization, or impairs its lubricating value by excessive reduction of viscosity.

Heat is received by all metal parts in contact with the hot gases and these parts include the cylinder head, inlet and exhaust valves, the walls of any valve pockets, the igniter plug, the piston head, and the whole interior of the cylinder wall exposed at the end of the outstroke. The heat received by the cylinder proper is greatest for the part exposed during the first part of expansion just following explosion, and extremely hot gases are in contact with the whole interior of the clearance space. In addition, heat is given up by burnt gases escaping through the exhaust valve and ports to the valve and its stem to the stem guides, port walls, and connecting parts of the cylinder head or the side pocket that carries the exhaust valve.

Heat received from hot gases must be conducted through the metal by more or less devious and rarely straight paths to the external surfaces of the metal walls from which heat may be abstracted. The first means of abstraction from the exterior faces of the walls is air in motion, induced or driven by a fan which may be separate, or the propeller itself. In some cases the free air moving past with the velocity of flight is relied upon, but the most unique arrangement is that of the rotating cylinder cooperating with the free air movement. The second means of abstraction is water or oil, or in general a liquid circulated by a pump, first over the heat receiving walls and then through the radiator where the free air again takes it up with or without the assistance of a fan. A third method, as yet used in very few aero engines, though frequently used elsewhere, is the boiling water jacket, noncirculatting, with an air cooled steam condenser and condensate return. In any case the ultimate disposition of the heat is to the free air, and when liquids are interposed as carriers it is with

the idea that some good results will follow what appears to be at first an indirect method. The only sort of good result that would be worth while is a better abstraction from heated walls in steadiness and degree, and that such is the case is unquestionable, not only on rational grounds, but by experimental demonstrations.

Whenever heat is to pass between a fluid and a body of metal, it has been established that a layer of fluid adhering to the metal as a film acts on the heat flow as an insulating layer. The thickness of this dead fluid film, and therefore its thermal resistance, depends on the condition of fluid motion, or, as it has been termed, on the scrubbing action. High velocities always reduce the film thickness and the thermal resistance. The thermal resistance (reciprocal of the conductivity) of gases and, therefore, of gaseous films of given thickness, is of the order of magnitude of 1,000 times that of metals and 10 times that of liquids and the thermal resistance of liquids 100 times that of metals.

Heat flowing from hot cylinder gases to the air directly must, therefore, pass through a complex path of at least three parts, a dead gas film on the inside walls of the cylinder, the metal wall and a second dead gas film on the outside. When a circulating liquid is introduced the path is more complex, consisting of a dead gas film on inside cylinder walls, the metal walls, a liquid film outside the walls, a second liquid film on the inside of the radiator, jacket, or water pipe walls, and finally a second gas film on the outside of radiator jacket or pipe. Each of these elements of the heat path exerts a thermal resistance to heat flow, and the resistance of the whole path is the sum of the separate resistances.

Heat flows according to a law similar to Ohm's law for electricity, inasmuch as the flow varies directly with the difference of potential or temperature, and inversely as the resistance. Therefore, over any complex path, consisting of several parts each of different resistance series as the same quantity of heat is passing through all, the whole temperature drop is divisible into partial temperature drops in the proportion of the partial resistance to the whole resistance. The resistance of any one part of the path is inversely proportional to the conductivity of the substance, is directly proportional to the length of path in the direction of heat flow, and is inversely as the cross section of path at right angle to the heat flow. Accordingly the temperature drop through a gas film is almost a thousand times as great as through a metal wall of equal thickness, and the drop through a liquid film also of the same thickness would be about ten times that through the metal. Gas film thicknesses and thermal resistances on the interior of the combustion chamber, because of lack of circulation there, must be fairly thick and so highly resistant. These interior gas film resistances must be much greater than the air films on the exterior where air is blasted over surfaces and very much more in turn than the resistance of films of liquids circulating over those exterior surfaces. Of all the temperature drops, by all odds the least is that through the thin cylinder walls when the flow is direct.

The object of the design of the cooling system is to keep the interior metal walls as cool as possible, and these walls will be cool in proportion as the thermal resistance of the heat flow path is greatest on the side of heat reception and in proportion as the resistance on

the outside is small and the heat flow path through the metal short, or in the event of this being impossible then of equivalently larger cross section.

By reason of the fact that they normally work at or nearly at full power and at such high speeds, aero engines develop more heat per square inch of wall interior than any other class of internal-combustion engines of the same bore, and it is an open question whether cylinder bore has much, if anything, to do with this quantity. Cooling must, therefore, be more effectively provided than in any other similar engine, so that careful study of heat flow conditions should be well repaid in improved results, both as to maintenance of high power and reliability. While considerable advance has been made in this direction it is more concerned with general system than with details. The literature, for example, is full of controversial matter on air cooling versus water cooling, on the relative merits of air blasted fixed versus rotating cylinders, and such matters of general arrangement, but there is a general lack of attention to the rational thermal analysis or design of the heat flow path for control of its resistances and temperature gradients.

Cooling of cylinder-barrel walls is perfectly easy by either air or water, but to get air cooling as effective as water the air must circulate many times faster than the water, which is quite effective, whether it has any material velocity or not. Extension of exterior surface is, of course, a direct and rational means of reducing the necessary air velocity to secure a rate of heat abstraction that will keep the temperature of the metal walls much nearer to that of the circulating air than to the interior hot gases. Such ribbing is quite unnecsary with water or oil in jackets as the rate of abstraction by this medium of higher conductivity is so high that no more abstraction surface is required than that receiving heat to keep the metal at a temperature very close to that of the liquid.

Difficulties of cooling begin only on the irregular parts and increase with their irregularity or thermal isolation from heat dissipators. The first irregular element met is the cylinder head or side valve pocket. This receives heat over the whole interior, including the valve faces, and also from the walls of the exhaust port. It can not be of uniform metal thickness, and by reason of valve seats and ports the metal heat flow path can never be of uniform length, so it is to be expected that however uniform in temperature the interior of the smooth cylinder barrel may be no such condition can apply to heads or valve pockets. The intake port and valve, with its stem and stem bearing, are coolers and need no other cooling than is available from the incoming charge, especially when the mixture carries some liquid still to be vaporized. It is this inlet self-cooling that is responsible in part for lowered volumetric efficiencies, so the heat exchange here that helps in one direction is harmful in the other.

Exhaust ports, whether cast in or welded to sheet metal or screwed into machined seats, can not be too well cooled, because they start at the exhaust valve seat, at which point heat is received on both the port side and combustion chamber side. Exhaust ports also carry the stem bearing of the exhaust valve, which is the only means of disposing of the heat received by the valve itself on either side. For the amount of heat received and to be disposed of, with-

out undue localized rise of temperature at the exhaust valve seat, these exhaust ports of cylinder heads or valve pockets are normally not cooled sufficiently. Increased metal cross section and metal extensions to jacket or air blast spaces would naturally assist. Still worse in many engines is the condition of the exhaust valve receiving heat on both sides and with no source of dissipation except its stem and the stem bearing. These stems should have a large metal cross section, and the metal should be of as high conductivity as possible, while the joint from valve stem to disk should be of long curve and the disk of increasing thickness toward the center to further promote conducting capacity. The stem bearing can hardly be too big or long nor too well cooled by sufficient metal and heat dissipating surface, but heat transfer from the stem to the guide bearing can hardly be expected without an adequate oil film, because a dry stem means a gas film of so much greater thermal resistance than oil as to render useless the large metal cross section and surface. To hold oil in such a stem bearing without an elementary stuffing box is, of course, almost impossible, but though such a device is not used, it should be added to replace the present two diameter stems now in use for this purpose. It requires only a casual survey of the illustrations of aero engines to see how different is the means for head cooling and expecially that of the exhaust valve, its seat, stem and port walls, and how easily, therefore, distortion of the metal parts may occur, due to unequal expansion, resulting possibly in breakages but certainly, when valves and seats are involved, in serious leaks which, once started, especially at exhaust valves, rapidly increase by the high erosion influences.

Probably the worst cooled part, aside from the exhaust valve, is the piston head, which receives heat over its whole top surface, equal to the area of the cylinder bore circle at least, and more if arched upward or dished down, as may properly be done, especially the former to give it some stiffness and elasticity in thermal expansion. This heat, while imparted in small part to the crank case air, must largely and almost wholly be disposed of to the cylinder walls by a radially outward conduction across the head, followed by conduct down the piston barrel, thence across an oil film to the cylinder walls. By increasing the metal thickness of the piston head regularly from the center outward in proportion to the square of the radius, its heat carrying capacity could be made proportional to the receiving surface above. Then by suitably thickening the upper barrel the axial heat carrying capacity can be made great enough to take what is delivered by the outer ring of the head and conduct it down for the oil film to be taken up and transferred to cylinder walls. This last transfer is most effective the longer the piston and the better the oil film, and as it is thus disposed of the thickness of barrel may be reduced. Such additional piston metal to secure an adequate heat carrying path will be least the greater its thermal conductivity, and there is no reason why suitable carrying capacities should not result without undue weight. Examination of the illustrations will indicate that apparently the idea of most of the designers has been to use as thin, and uniformly thin, metal as possible with no thought of heat conductivity whatever, though a few give evidence of some grasp of the problem. An exception to the overheated piston is found in the rotating cylinder engine that carries its inlet valve in

the piston, which in this case is adequately cooled, but at the expense of volumetric efficiency. There is no reason, should thick metal pistons prove objectionable, why air blasts should not be introduced directly under the pistons except the consequent evaporation of lubricating oil.

Piston heads that are very unequally heated or very highly heated are subject to a considerable expansion and to oxidation as well, besides being responsible for decreased volumetric efficiency and preignition or lowered compression. Excessive and variable expansion of the head besides resulting in permanent deformation or cracks will cause the piston to bind on the cylinder unless cut away or given extra cylinder clearance. If sufficiently cut away to give relief, leakage is promoted, which defeats lubrication, and the oil film, which is an essential part of the thermal path from piston to cylinder, is destroyed and overheating accelerated. Some little clearance, and more at the top than along the barrel, is necessary, but the less the better, and the better the cooling of the piston head whether by conduction across it and down the barrel or through separate conduction bars, directly from head center to barrel and to oil film, the less clearance will be necessary. A photograph is given in a German report of a piston that failed from overheating, and such failures seem to be frequent. There is also shown a burned spark plug, which should be cooled just as well as other parts to prevent excessive temperature rise, though its end must be warm to promote cleanliness, but not so warm as to make an incandescent spot, or to cause destruction.

Cracked cylinders are also more or less common from unequal cooling, and in both the German and the British Alexander tests such cases are reported. In the latter the fact that the cylinder ran 11 hours before failing proves the crack to be not due to any gas-pressure stress. This unequal cooling or heating may be due to uneven thicknesses of metal or to unequal heat abstraction, as would occur in water jackets with steam or air pockets, or to the impact of the air blast from the propeller on the front side of a forward cylinder. Rotating air-cooled cylinders and, in fact, even fixed air-blasted cylinders can not be equally cooled because it is quite impossible to force equally cool fresh air at equal velocity around the whole cylinder, no matter how many baffles or guides are used, and this inequality must promote distortion. One compensating element used, that of eccentric ribs giving more surface for heat abstraction on the side of least air activity, is ingenious, probably more so than effective. There seems to be no hope whatever of air cooling ever being made as uniform as with water, and therefore more distortion effects are certain in air-cooled engines even though, by the use of excessive quantities of air and fan or windage power, the walls could undoubtedly be kept as cool as with water, it could not be a uniform cooling, and hence not as desirable. In the German test report the windage of the Gnome rotating cylinder engine is given as 8 per cent of the output, which checks exactly the value given by Winkler for the Renault fixed-cylinder engine fan power.

Water gives control of temperature in degree as well as uniformity, for with sufficient radiator capacity the water temperature entering

jackets can be kept only a few degrees above that of the free air. By sufficient circulating-pump capacity the delivery temperature from the engine jackets can be kept as near the inlet temperature as may be desired. On the other hand, should the engine be found to work better with warmer water, or if radiator size is to be minimized, and the advantage be regarded as greater than a warmer engine, this can be accomplished by reducing radiator size with corresponding rise of temperature of water inlet to engine without in any way affecting the uniformity of heat abstraction from the engine metal. The limit of this occurs when the jacket water is allowed to boil, as in the Antoinette, in which case the radiator becomes an air condenser and very small because of high temperature difference between steam (212° F.) and the free air. Higher temperatures than this can be secured by the use of oil in jackets, as is done in some farm tractors to further reduce radiator size, and such oil has the advantage of not freezing.

Piston-cooling effectiveness is more or less measured by the limiting diameter that is operative, and the tendency to use multiple cylinders of small diameter, especially in the rotating air-cooled engine, which go as high as 20 cylinders per engine, and to keep their cylinder diameters less than 5 inches, can be traced directly to this. Even with water-cooled engines a limit is reached, dependent entirely on this piston-cooling factor, and larger cylinders than are now used require better cooling of the piston by the methods indicated.

Temperature expansion stresses added to those imposed by gas pressures and mass motion forces have never yet been successfully attacked by the stress analyst, but even if they could be treated mathematically it would help but little when the temperature in the various parts of the metal structure are unknown. No class of machine except the large internal-combustion engine suffers so severely from these temperature conditions as aero engines, and in none is the consequence of failure likely to be so serious. This new and difficult problem must be attacked patiently and systematically by experimental research if any but accidental or haphazard results are to be attained. Pending such needed fact data on temperatures and temperature gradients and on the effects of mean temperature or temperature differences on volumetric efficiency, on limiting compressions, on metal expansion, on permanent distortion, or on corrosion, the best that can be done is to use that method of attack that promises best results in uniformity of cooling and in low mean temperature. This undoubtedly involves the use of liquids as heat receivers from the metal walls, but just as surely demands proper arrangement of metal parts for promotion of heat transmission as uniformly as possible through the several parts.

Lubrication as a process is of considerably greater importance and significance in the aero engine than in any other, for while it has but little direct relation to the power weight ratio, it has an indirect one and, of course, bears directly on reliability, constituting probably the most important element of this factor. The indirect relation of lubrication to the power weight ratio results from the use of unusual metals at bearing surfaces, especially cylinder versus piston, adopted for reduction of metal volume, and bringing cast iron and bronze against steel, and even steel against steel. Lubrication is also as pointed out previously, a factor in cooling when the heat dissipation

path includes an oil film surface, maintenance of which reduces heat resistance to a proper value, but loss of which results in overheating of the parts that are thus thermally isolated. Not only is the lubrication of the aero engine peculiar in these two respects of unusually difficult metals to be lubricated, and heat conductivity function in addition to that of lubrication, but in other respects as well. Maximum compactness in the interests of low weight leads to the use of small bearings and as high bearing pressures as may be feasible for the very high speeds in use. In the case of rotating cylinder engines any change in angular velocity produces piston side thrust loads, not found in any other machine and these may be extremely high, so high as to even bend the cylinders as cantilever beams if the acceleration, positive or negative, is large. All aero engines have closed crank cases and these must necessarily get very warm, largely from heat received from the underside of pistons, but also from the whole side of the piston barrel and the exposed cylinder wall. The cylinder wall is hot by reason of the heat being conducted through, so that the viscosity of the oil on it is reduced just about to the limit. In the hottest region near piston heads, and even in some cases in other parts as well, the cylinder oil suffers decomposition changes, due to the heat, as is proved by the progressive loss of lubricating value of oil in circulating return systems. Not only is the oil subjected to variable and high temperatures, but it must be of such character as will not leave excessive carbon residues in the combustion chamber when it works past pistons, but must vaporize on the hot surface with least carbonization. Coupled with these high interior temperatures of the aero engine are possible excessively low temperatures of the surrounding air, freezing temperatures in high altitudes being rather the rule than the exception, and yet immediately before or after, the machine may be close to the earth where the temperature in summer may exceed 100 degrees.

It is clear that aero engine lubrication is not only more important as a process than in other classes of engine with reference to need and consequences, but is very much more difficult on account of the excessive heating, even when the engine is built of the standard materials of internal combustion engine practice, i. e., cast-iron piston on cast-iron cylinders, but is doubly difficult when steel is substituted to reduce metal volume, so it is natural to find new elements of practice introduced.

Crank shaft and crank pin bearings of aero engines offer no more difficulty on aero engines than on others, provided the bearing pressures imposed by the designer in an effort to cut down material are not excessive and provided the surrounding atmosphere is not hotter. The necessity for crank cases imposed by the presence of dust in the air at landing and starting points, does make the atmosphere surrounding these bearings abnormally hot, especially when the pistons are inadequately cooled as is more often the case than not. This hot atmosphere created by hot pistons and conserved by the closed crank case naturally raises main and crank pin bearing temperatures to some value higher than the crank case air, fixed by the heat generated in them by friction, and so reduces oil viscosity correspondingly. This would seem to be sufficient reason for using lower bearing pressures or larger surfaces than in auto engines, for example, and this conclusion is reenforced by the fact that the bearing surface speed is so

very high and continuously so. Instead of larger main and crank pin bearings, the aero engines so far developed usually have equal or smaller ones than automobile or boat engines. No matter how elaborate the oil-feeding system nor how carefully the grade of oil may be selected, this practice can not be accepted until it has been more fully demonstrated than has yet been done, that it is necessary.

Piston and wrist pin lubrication present still greater difficulties, and no new methods of lubrication are available beyond the supply of excessive quantities of oil to these surfaces. As already pointed out, aero-engine pistons are hotter than those of other engines because of the higher speed and consequent greater heat quantity per minute taken up by the pistons, and also because these are of thinner metal and so can not dispose of their heat so readily to the cylinder walls. This is further aggravated by the shortness of the pistons, which in some cases are hardly more than two-thirds of a diameter in length, though Winkler recommends 1.1 diameter, while stationary-engine pistons are regarded as requiring a length of two diameters. Such short pistons reduce the heat dissipating cylinder contact surface, but also increase the side-thrust pressures. They tend to cock sidewise, especially when made loose to relieve expansion, and so concentrate side thrust at the ends instead of distributing it over the already too small surface. In the rotating cylinder engines additional side thrust of almost any amount may result from variations of angular velocity if sudden. Under such high temperatures and high side pressures, perhaps badly distributed, the viscosity and lubricating value of most oils falls very low and the decomposition conditions are approached with production of light constituents that evaporate and of tar or carbon constituents that stick. Yet in spite of this the speed of the rubbing surfaces is so very high as to require lower surface pressures and temperatures rather than higher. Mean piston speeds are never under 1,000 feet per minute, a high limit for good stationary-engine practice, and even exceed 2,000 feet per minute.

To still further aggravate this piston-lubrication condition, steel pistons have been introduced against cast-iron cylinders, steel cylinders with cast-iron pistons, and steel pistons against steel cylinders, again in the interest of reduction of metal volume, though nowhere in engineering practice has there been any success in lubricating such surfaces, especially when very hot.

The fact remains, however, that these aero engines do run, but the absence of sufficient reliable data extending over years of experience, commensurate with that on which present standards of internal combustion engine practice rests, makes it a source of wonder whether the lubrication of aero engines at present is wrong and bad, or whether on the other hand they have taught old practice something new. About all that can be said at present, however, is that many aero-engine failures traced to lack of lubrication are recorded; that the oil comsumption of these engines is very high, in some cases reaching half the weight of fuel; and finally that the greatest caution should be observed in following present methods. At the same time, the construction of engines to operate cooler at lower bearing surface pressures and with parts of successively different materials should be undertaken for test data. Each new combination should, be experimentally tested to destruction with decreasing quantities of

selected but different oils to definitely settle this question in the laboratory.

As to details of method of application of oil, there seems to have been developed some more or less general practices. All rotating cylinders are lubricated by crank-case sprays, which in the case of those taking the charge through the crank-case involves the carrying of appreciable quantities of oil into the combustion chamber where it burns, at least in part. This is practically equivalent to the splash system for fixed cylinders, which for auto engines has proved only moderately successful and for aero engines is quite unsuited. All fixed-cylinder engines use forced lubrication for main and crank-pin bearings, through hollow or drilled shafts and cranks, the pressure being developed by pumps, many of which have failed even during competition tests. Normally these fixed-cylinder engines have crank-case oil tanks at the lowest points, often, though not always, carrying here all the oil supply for a full length run of 10 hours or more, as a means of preventing solidification of oil under low-air temperatures, and with all or most of the distribution pipes inside the crank case for the same reason, sometimes substituting cored or drilled passages in the casting for pipes. These pump-forced feeds are so far all of the central system, one pressure supply, sometimes with a duplicate in reserve, being provided with multiple outlets, which has an element of danger, because tight bearings needing most oil receive least in proportion to the loose bearings which, offering less resistance to oil escape, tend to take it all. There are three typical pump systems: First, complete circulation of the whole supply to bearings with gravity return to sump and pump; second, direct feed of fresh oil from pump with no return; and third, combinations of this with two pumps, one for fresh and one for circulating oil, discharging into common bearing tubes or into separate ones. Any circulating oil system requires a cooler, and the exposed crank-case sump surface is sometimes relied on, sometimes supplemented by air-circulation tubes or by carrying the oil supply to exterior cooling surfaces, and as a rule this oil cooling is made complementary to carburetor mixture or air warming, by passing one in thermal contact with the other. As a rule cylinders and wrist pins are lubricated by the oil escaping from main and crank-pin bearings, but considerable modification of details is found, and reference is made to the papers and reports reproduced in the appendix. Among these that of Benderman, reporting on the second German ocmpetition, is so good that it is worth quoting.

Lubrication.—The amount of lubricating oil required is affected by the system of lubrication and the circulation of the lubricant. The lubricant of an aeroplane engine should not only reduce the friction between the parts which are in sliding contact, and not only remove the frictional heat, which is considerable, due to high bearing pressure, but in many cases it also has to cool the piston heads. The oil is largely lost without doing any work. It works past the piston into the combustion chamber and there fouls spark plugs and valves. This, of course, can not be avoided altogether, but it may be minimized by guards at the cylinder ends and by positively feeding the oil to the wrist pins. Much oil escapes in the form of vapor and fog through the ventilating funnels (breathers), which equalize pressure or vacuum in the crank case without allowing the oil to squirt out or dirt to

enter. If these breathers are made long and exposed to the air blast the oil vapor will condense in them and distant places, such as the cam shaft above the cylinders, may thereby be lubricated in place of the hand lubrication.

The loss of oil by leaks in the casing depends on the number and kind of the joints. Especially the guides of the valve tappet rods throw out a great deal of oil. It will, therefore, be well to keep their diameters at the place where they emerge, small. In one motor the tappets are nearly surrounded by the ventilating pipes (breathers), which direct the oil coming back to the crank case.

The lubricating qualities of the oil decrease with increasing temperature. Therefore rapid circulation of the oil in the bearings subjected to high pressures is required; also sufficient cooling in a spacious oil pan, preferably with cooling tubes. At high temperatures as tables 5 shows, castor oil is considerably more viscous and effective than good mineral oil. It, therefore, so far can not be done without in air-cooled engines. For water-cooled engines one of the two mineral oils mentioned was always satisfactory during the competition.

The most simple system of oil distribution is the so-called splash system (very imperfect). The fresh oil supplied from outside or the storage oil collecting in the crank case is whirled around by the rotating and reciprocating parts and is thus intended to get to the proper places. This means that considerable excess of oil is required; the losses are considerable. Engines lubricated in this way usually have a smoky exhaust.

More advantageously the oil is positively conducted by a distributing line to the fixed bearings, and from there as far as possible without loss conducted to the connecting rod ends and to the rubbing surface of the piston. This is best effected by full oil throw rings on the crank and a pipe connection between the ends of each connecting rod. In some cases the oil throw rings are only partially executed and are partially replaced by turned grooves in the side of the crank. These catch the oil, which, after leaving the bearings, runs along the side of the crank.

In other cases the oil conducted to the crank bearing is forced into the interior of the crank shaft and from there under the influence of centrifugal force runs to the connecting rod ends. On the way into the shaft it has to overcome centrifugal force. That requires very neat bearings and at times high oil pressures. Piston force pumps in this case are to be preferred to gear pumps. The positive supply to the wrist pins permits the most complete utilization of the oil. The lubricating oil consumption is reduced and a supply for several hours may be provided in the moderately enlarged crank case. If the crank case should be too small, a pump for fresh oil has to replenish the supply from without. The fresh-oil pump may either discharge into the circulation line or may feed a special distribution net, separated from the closed-circuit line. This, however, is hardly advantageous, since the required small make-up of fresh oil, should the closed circuit fail, does not suffice to keep the engine running for any length of time. Special attention must be given to the fact that the oil in cold weather becomes so thick in exposed pipes that a dangerous lack of oil will be the result and the bearings will melt.

The circulating oil becomes polluted by metal dust and deposits of combustion. Small particles, however, do not matter; larger

ones may be kept away from the pump by brass screens. In the engines tested these screens were not always well accessible. From the fine carbon particles which the circulating oil carries with it after a certain length of time, the bearing metal receives a grayish look, but its durability is thereby increased.

The oil pump is connected by a short suction line with a point of the case located so low that in all inclined positions of the engine it is covered by oil. The lubricating oil, which is very thick at low temperatures, renders the design of the oil pump very important. All automatically operated parts, such as valves with springs, and such, easily fail, and therefore are to be avoided.

Part 2 (b).—GENERAL ARRANGEMENT, FORM, PROPORTIONS, AND MATERIALS OF AERO PARTS—POWER-WEIGHT RATIO, RELIABILITY, AND ADAPTABILITY.

If in every cylinder the same mean effective pressure were obtained, and if all cylinders weighed the same number of pounds per cubic foot of displacement per stroke, including their attached valves, rods, pistons, wrist pins, and connecting rods, then the weight per horsepower of engine at the same engine speed would depend on the frame and shaft weights per cylinder which is a result of the general arrangement. If at the same time the thermal efficiency of all engines were the same, the added weight of fuel and tanks per horsepower would be the same for all. Differences in weight per horsepower of engine proper and of engine, oil, fuel, radiator, and tanks taken together are considerable, the heaviest being more than twice the weight of the lightest even for short runs, and the excess is more than this for the longer runs. The basic causes for such differences can be reached only by analysis along these lines, and such analysis will indicate that as many of the elements of actual difference are accidental or incidental as are essential or inherent in arrangement, form, proportions, or material.

The influence of arrangement to be first examined is in some cases quite clear and in others complex. Where, for example, arrangement of cylinders in number and position has no effect on the limiting speed, on the mean effective pressure, on thermal efficiency, or on the weight of cylinders complete per cubic foot of displacement per stroke, then the effects of arrangement are clear, qualitatively. The contrary is the case when a given arrangement that gives reduced frame and shaft weight per cylinder as compared with another also requires heavier cylinders, or is limited to a lower speed, or is incapable of any but a low mean effective pressure, for here the result depends on the degree to which one factor compensates another.

Differences in arrangement are more bold and numerous in aero engines than in any other class, and some of them are quite unique, yet with these truly remarkable differences that are quickly grasped by a reference to the illustrations in the appendix, the surprising thing is not that the weight per horsepower varies considerably with arrangement but that it does not vary even more. This is an indirect proof of the existence of these compensating factors, and shows that arrangement has not as great an effect on weight per horsepower as might at first be expected. Air cooling versus water cooling is a fair illustration of this, for elimination of jacket, radiator, and pipe metal and of water reduces weight, of course, but the result is usually a

lower mean effective pressure and thermal efficiency. Again, the rotating cylinder air cooled as compared with the fixed cylinder, while eliminating fans and rib casings, adds a windage power requirement, must have steel cylinders to avoid the uncertainty of casting soundness in resisting the great centrifugal forces, and so must use excessive quantities of oil, which has to be carried.

Ignoring for the present those compensating differences and concentrating attention on the effects of arrangement alone, it is clear that two similar cylinders set side by side, each developing the same power and of equal thermal efficiency, will not require shaft and frame weights twice as great as one. Adding a third is equivalent to placing between the frame and shaft ends an intermediate piece without ends, and hence of less weight, but each cylinder added, beginning with the fourth, adds exactly the same frame and shaft weight as the third, and therefore has very little influence on weight per horsepower, unless other modifications are introduced, such as casting two cylinders en bloc, removing main bearings between alternate cranks, and thickening of frame and crank shaft to meet the stresses introduced by increased lengths. Therefore multiplication of similar cylinders along one line reduces weight per horsepower fast at first, and beginning with four rapidly less, and beyond a certain number of cylinders the weight reduction is more or less equalized or overbalanced by the necessity for greater metal cross-sections per foot of length in shaft and frame. To illustrate the point, a given style of boat engine having the same cylinder on engines of one, two, three, four, and six cylinders in line is selected, as no other class of engine covers such a wide range of number of identical cylinders. For one size of cylinder the single-cylinder engine weighs 472 pounds, and the two-cylinder engine 626 pounds, the second cylinder having added 154 pounds, or 33 per cent. The third three-cylinder engine weighs 716 pounds, so that the third cylinder has added 90 pounds, and each additional cylinder also adds the same 90 pounds up to six, the weight of which is therefore that of the two-cylinder engine, 626 pounds, as these are retained for ends, together with the weight of four cylinders of 90 pounds each between, or $360 + 626 = 986$ pounds. The corresponding weights per horsepower have the following relation, taking that for one-cylinder engine as unity, the numbers representing 1, 2, 3, 4, and 6, respectively, are 1, 0.52, 0.40, 0.335, 0.274. The fact that each intermediate cylinder has added exactly the same weight in this engine indicates that shaft and frame weights per foot have also remained constant, but in some cases, and properly, these are made heavier in passing, for example, from four to six cylinders, so that the small reduction in weight per horsepower above 5 per cent of the weight of the single-cylinder engine is lost entirely, and the six-cylinder would be no lighter than the four per horsepower.

Further weight reduction by arrangement alone is available with multiplication of similar cylinders, not in line axially in a plane passing through and including the shaft, but radially about the shaft in a plane at right angles to it. Two cylinders with axes in line and with connecting rods working on one crank pin, constituting the two-cylinder opposed engine, or two cylinders with axes at right angles also working on one crank constituting the right-angled V engine, add no frame weight for the second cylinder over what the first requires. It really reduces it by the metal required to cover the bore

hole, except for some thickening at the joints. Nothing at all is added to the shaft weight except when the crank pin is made longer, as is rarely the case. This arrangement gives a greater gain in weight per horsepower than two cylinders in line, but when the second cylinder is added radially in another plane and has its own crank it should result in a weight exactly the same as for two in line, because the difference is merely one of rotating one cylinder with reference to the other, retaining the same metal throughout.

These are the two fundamental arrangements of multicylindering for the standard piston-connecting rod-crank engine, and so long as the cylinders remain fixed there is no reason why each cylinder in any combination should not weigh the same and give the same mean effective pressure or thermal efficiency as any other. In this case the weight per horsepower of engine and plant is less the more the cylinders are multiplied and the more the multiplication takes place radially around one crank rather than with separate cranks, up to the point where the shaft and frame thickening must be so great as to compensate for reductions, which begins to be appreciable at four cranks and is very marked at six, except as other details may modify the result.

Fixed-cylinder multiplication radially about one crank presents no objectionable features until the cylinders become inclined differently to the normal horizontal plane, when there enter lubrication difficulties on cylinder-piston surfaces, especially when cylinder heads are lower than the crank shaft. The tendency for oil to work past the piston into the combustion chamber, fouling spark plugs or carbonizing the interior and requiring more oil to keep the surface properly wetted, is strong enough when the head is directly above the shaft, but is stronger when it is lower, and doubly so when the head is directly below. This has prevented the general adoption of any radial arrangement about one crank beyond the horizontal opposed and the 90° to 45° V, set with equal angles to the horizontal. Any more than two radial cylinders compose unequal angles and involve different tendencies to oil flow toward heads in each, so while multiplication in this direction promises greater weight reduction than in line with a crank to each cylinder, the latter has been carried farther in point of general adoption.

The four and six cylinders, each with its own crank, are standard, and doubling the rows of cylinder axes in line without changing the cranks gives the 8 and 12 cylinder opposed, the former used a little, the latter not at all. It also gives, when axes are inclined, the 8-cylinder V, a much used standard, and the 12-cylinder V, but little used so far, but possessing advantages that are promising.

Radial disposition of fixed cylinders which should give the greatest possible weight reduction in frame and shaft has a few representations, notably the air-cooled Anzani, which uses three or five cylinders in one plane on one crank and then duplicates on successive cranks until the 200-horsepower engine is reached, which has 20 cylinders in four planes of five stars each, and five cranks. It is the operation of this and similar engines and of the bold departure of the German Daimler inverted cylinders (Bendeman report), with heads directly under cranks, which makes it doubtful that the old conclusion that such arrangements must lead to fouling is really valid. This latter engine did not foul in the competition, and it will be worth watching in service to see if it continues to keep as clean as do cylinders with

heads above cranks, and not to require excessive amounts of oil to make up for gravitational cylinder wall drainage. If this should work at all right, this arrangement offers further opportunities for weight reduction over the now standard multicrank form.

Even here, however, there is a limit to the number of cylinders that can be radially placed about one crank, a limit imposed by their intersections, and while the rotating Gnome uses a maximum of nine and a minimum of five, the fixed Anzani uses three or five. The Anzani figures for two sets of three are 50 horsepower and 200 pounds, or 4 pounds per horsepower, and for two sets of five 100 horsepower and 330 pounds, or 3.3 pounds per horsepower, the reduction of 0.7 pounds per horsepower, or 17½ per cent, being the effect of using five instead of three per star, all cylinders being of same size. Similarly the effect of doubling the number of rows is shown by comparing the 10-cylinder 100-horsepower with the 20-cylinder 200-horsepower, both having sets of five, the former two sets and the latter four sets. The former weighs 363 pounds, and the latter 682 pounds, the difference of 310 pounds being the weight added to the first 10 cylinders, which themselves weigh 363 pounds, and showing nearly proportionate addition of weight per crank added, the actual addition being 88 per cent. The gain is of course greater in passing from a one crank star to a two than from two to four cranks, as might be expected from the study of cylinders in line. This is shown by the figures for the 3-cylinder, 30-horsepower, 121 pounds, compared to 6 cylinders (two sets of 3 50–55 horsepower, 200 pounds), the second row adding 79 pounds to the first 121 pounds, which is only 65 per cent, as compared with 88 per cent when two rows are added to two to make four.

Increase of cylinders radially about a crank always reduces weight, but the weight reduction is most when the frame and shaft weight is large in proportion to cylinder weight, and least otherwise. Ideally the weight reduction by multiplication of cylinders would be zero if the shaft and frame weighed nothing. This is clearly shown by the figures given by Winkler in Table VII for the proportionate weight of the various parts of fixed auto type and rotating radial cylinder engines. To these figures are added some pound values for the parts computed from Winkler's fractional weights and assumed typical total weights.

TABLE VII.

[NOTE.—The table is based on Winkler's figures for weight distribution in different types of engines. The first three engines are of the fixed cylinder in line type; the last is an ordinary Gnome engine. The total weights have been assumed.]

	100 horsepower 4-cylinder engine.		55–60 horsepower 4-cylinder engine.		150 horsepower 6-cylinder engine.	
	Per cent.	*Pounds.*	*Per cent.*	*Pounds.*	*Per cent.*	*Pounds.*
Crank case, complete	23.75	95.00	19.00	49.40	23.00	126.50
Cylinders	26.00	104.00	30.00	78.00	28.50	156.80
Pistons	5.75	23.00	8.50	22.10	7.00	38.50
Connecting rods	6.50	26.00	5.00	13.00	9.00	49.50
Crank shaft	15.00	60.00	14.50	37.70	13.00	71.50
Cam shaft	3.25	13.00	2.00	5.20	2.00	11.00
Valve rods, etc	5.50	22.00	4.50	11.70	4.50	24.75
Valves, springs, etc	3.25	13.00	2.00	5.20	3.50	19.25
Pump, including connections	1.50	6.00	2.75	7.15	1.50	8.25
Carbureter, throttle, etc	.50	2.00	1.50	3.90	.50	2.75
Magneto, etc	7.50	30.00	7.00	18.20	6.50	35.75
Oiling system	.50	2.00	1.25	3.25	....	....
Rest	1.00	4.00	2.00	5.20	1.00	5.50
Total	100.00	400.00	100.00	260.00	100.00	550.00

TABLE VII—Continued.

	Rotating-cylinder engine.			Rotating-cylinder engine.	
	7 cylinders.	50 horsepower.		7 cylinders.	50 horsepower.
	Per cent.	*Pounds.*		*Per cent.*	*Pounds.*
Crank case	20.00	30.00	Magneto	7.50	11.25
Cylinders	27.50	41.25	Oiling mechanism	2.50	3.75
Pistons	7.00	10.50	Carbureter, including throttle	1.25	1.875
Connecting rods	6.00	9.00	Frame	9.50	14.25
Crank shaft	8.00	12.00	Rest	1.00	1.50
Cam shaft and drive	2.00	3.00			
Cam-shaft casings	3.75	5.625	Total	100.00	150.00
Tappets and rods	4.00	6.00			

These figures are most interesting, but must be used with considerable caution, as the Winkler fractions are general averages and when applied to a given engine may give pound values that are somewhat in error. One instance of this appears in the value obtained for the magneto in pounds by applying the general average fraction to a given overall engine weight and which works out in the table as 35 pounds for one and 18 for another. While of course there really may be this difference, it is not fundamental nor is there any acceptance of its accuracy. The really valuable parts of the table are those items for the principal parts, such as cylinders. crank case, pistons, and shafts.

Radial disposition of cylinders does not suffer from inequality of oil flow to combustion chambers only when cylinders and frames are rotated about the crank shaft, but here the tendency toward headflow is increased by the centrifugal force on the oil, which is far greater than pure gravitation and which apparently is at least a contributing factor to very high oil consumption of these engines and their quick carbonization. It may be that this is more an effect of the use of steel and of high wall temperatures than of centrifugal flow, as such engines are always air cooled by reason of the difficulty of making moving water joints and of controlling water flow with the centrifugal forces acting in jackets and pipes, but everything points the other way. Inverted cylinders having head flow tendencies between these rotating cylinder engines and the normal vertical must be accepted with great caution at present, though there is at present no data that warrant a conclusion. Complete radial star disposition of rotating cylinders gives the smallest possible frame and crank weight per cylinder, but it is not possible to use some of the cylinder constructions and materials that are perfectly feasible in fixed cylinders. Centrifugal forces put cylinders and connecting rods under a tension stress that is pretty large at the high speeds used, and angular velocity changes impose cylinder-bending stresses, due not only to their own overhang but also to the pistons, and these stresses are additional to those imposed by explosion pressures. To reduce these special centrifugal stresses to a minimum, the weights of the parts must be the very least possible, and this is to be accomplished by the use of an assuredly sound and high-tension metal, such as one of the steels. These engines, then, have adopted steel as a cylinder material not so much from choice as of necessity,

and the fact that the surfaces could be lubricated at all has acted as an incentive to its substitution for the old standard cylinder material, cast iron, in the fixed cylinder engines, with corresponding weight reduction per cylinder in that class. The effect of this weight reduction must not be exaggerated. Steel pistons, for instance, are only 12 to 15 per cent lighter than cast-iron ones, since bottom must not be too thin on account of the danger of burning through. Furthermore, pistons weigh only about 7 per cent of the total engine weight. Greater effects are possible when steel cylinders and sheet jackets are substituted for cast iron, yet even here the gain is rather less than might be expected, because of the heads, and the substitution is warranted more on grounds of assumed soundness of forged rolled or drawn steel compared with cast-iron, which may have hidden defects such as blow holes, cold shorts, or bad shrinkage stresses.

In this brief review of the effects of general arrangement of cylinders and cranks on the weight per horsepower, it was assumed that other factors remained fixed, such, for example, as the weight of cylinders per cubic foot of displacement per stroke. Variations in details of construction of the cylinder complete with valves and valve drives, pistons, and connecting rods, such as might affect this unit weight, are not only pretty numerous and cover a considerable range, but taken in conjunction with the corresponding variations of material, the resulting unit weights of the complete cylinders follow no simple law. A type construction of few parts that would tend to lightness may employ a heavier material that equalizes the weight. A somewhat more complicated or essentially heavier construction will often be found associated with a lighter material, producing the same result and unit weight. The combination of lighter construction and material together, cooperating to produce low unit weight, is also found, but unfortunately this is usually offset by lower mean effective pressure and efficiency or by a less favorable general arrangement.

The object sought is the lightest combination of form and material for cylinders, pistons, and their accessories consistent with proper values of the other factors that contribute in the same direction to a higher horsepower per pound of total weight.

It seems pretty clear that designers and inventors of aero engines have started with some favorite general arrangements of cylinders, cranks, and frames and then have selected detail part forms and such material for cylinders and pistons as was either essential, as in the rotating cylinder engines, or as would bring the net result into successful competition with previous engines. To put it otherwise, there is no combination of the various factors that contribute to a low weight per horsepower ratio involving the most favorable value of each factor. This would require the largest number of cylinders that could be disposed radially about one crank, followed by further extension in line on other cranks, as to general cylinders-frame-crank arrangement. It would also require the use of the simplest piston, cylinder, valve, and connecting rod construction, all of steel, operating at the highest speed, and processes, and producing the highest mean effective pressure and the lowest fuel and lubricating oil consumption. Such a combination has so far been impossible and is mentioned here to accentuate the position of the factor at present

under consideration, that of weight per cubic foot of displacement per stroke of cylinders, including all attached parts.

Lightness of metal parts may be secured by the use of large volume of low density material of low stress resistance such as aluminum or by a small volume of metal having high stress resistance but of greater density, such as steel, or some compromise, such as cast iron. If the material were required to perform the stress resistance function alone, the modern steels which can be counted on for upward of 175,000 pounds per square inch elastic limit and some 15 per cent elongation with an ultimate tensile strength approaching 200,000 pounds per square inch, are so superior that nothing else could be considered. That other materials are used at all is due to the fact that the material of some parts must have other properties, each contributing to a different function than that of stress resistance. Piston and cylinder material must have good conductivity, especially the former. Pistons and exhaust valves especially, but to some extent the whole combustion chamber, must resist oxidation under high temperatures and water jackets must resist hot water corrosion. All heated parts should have the lowest possible coefficient of expansion to minimize the thermal stresses of unequal heating, and the expansion characteristics of cylinder material with reference to that of the piston should be such as to oppose seizing on heating. The piston must heat more than the cylinder, so cylinder material should have a higher thermal coefficient of expansion than piston material, though in small cylinders with proper clearance the same material will serve but never should piston metal have a higher coefficient than cylinder metal. Permanent distortion of metals under the heating conditions of operation is not permissible in cylinders, heads, valve seats, valves, and pistons, so some commercial alloys, including some steels, are barred on this account. Finally the metal of these two parts, cylinder and piston, should have such a molecular structure as will lubricate well, cast iron on cast iron is the best, cast iron on steel next best, and steel on steel the worst combination, neglecting the nonferrous alloys which may be serviceable though they are as yet unknown quantities. This is not an absolute necessity except where excessive oil consumption is more important than metal weights. Engines intended for short flights, an hour or so, might very properly have piston-cylinder materials that ignore this, compensation being secured by large oil consumption which adds little weight. But long flights will add enough oil weight to more than offset the weight reduction obtained by making both parts of steel, as compared with both cast iron, or one of each.

About every combination of standard ferrous materials forged, cast, drawn, and rolled for the heated parts that could be produced has been tried, and is even now in use, so it can be definitely stated that practice in ferrous materials is not yet established, which means that there are insufficient data at hand on the differences in their behavior and practically none on the nonferrous. Here is a field for investigation that is of most fundamental importance practically untouched metallurgically, and solution of which requires scientific research under the combined efforts of enginemen familiar with the requirements, of metallurgists familiar with alloy production and properties, and of shopmen familiar with the processes of forming and fitting.

No metal equal to cast iron on cast iron has ever been found for the pistons and cylinders of internal-combustion engines in all the desired properties except one, that of metal weights for a given size. Casting, as a process however, is most uncertain; the known defectives amount to almost 50 per cent while the unknown possibilities and hidden defects are responsible for large factors of safety and the use of excess metal. This excess is quite prohibitive and fruitless in rotating cylinders with the enormous centrifugal stresses that come from speeds exceeding 1,200 revolutions per minute, because each pound excess metal adds its own equivalent centrifugal stress and so fails to add to the certainty of safety as in fixed cylinders. Excess thickness adds to the resistance to heat escape through cylinder walls. It was in these rotating cylinders that the first departure from the older internal-combustion engine practice took place, from sheer stress resistance requirements regardless of other properties. The steel cylinder machined from a forged-steel billet was developed by the French rotating cylinder engine builders, and with cast-iron pistons it operates successfully.

Some builders of fixed cylinder engines encouraged by this demonstration adopted steel for cylinders with cast-iron pistons. Even steel pistons, were tried and in some cases adopted for use in both steel and cast-iron cylinders, apparently without gain, in the former case because of increased lubrication requirements and in the latter from reversed expansion coefficients or permanent distortion. Some of these steel fixed cylinders are cast with heads in one piece and machined all over to disclose defects, but in other cases rolled or forged steel cylinders are combined with cast-iron heads in which ports are most readily formed. The most radical of all these steps is undoubtedly that undertaken by the German Daimler Co. in constructing cylinders, heads, ports, valve seats, and jackets, all of sheet steel welded together by the modern oxygen flame method. Only experience can tell how successful this may prove in practice, though in the competition tests the engine gave a most remarkable performance.

At the present time the only data bearing on the question are those of oil consumption, Table VIII, with respect to materials. This is not a basic figure anyway, and is complicated by variations in oil and in oil application methods, so it is inconclusive though interesting.

Table VIII.—*Oil consumption versus engine type and cylinder piston materials.*

Cylinders and cooling.	Class construction.	Materials.		Engine name.	Authority.	Oil per HP.-H.
		Cylinder.	Piston.			
Water-cooled fixed cylinder.	4 cylinders in line..	Cast iron..	Cast iron..	100-horsepower Benz.	Bendemann...	0.042
	6 cylinders in line..	...do......	...do......	100-horsepower Daimler.	....	.031
		Steel......	..do......	90-horsepower Daimler.	Bendemann...	.038
			Steel......	Austro-Daimler...	Maker.........	.027
	8-cylinder V........	Cast iron..	Cast iron..	140-horsepower Sturtevant.	.....do........	.045
		..do......	Steel......	150-horsepower Sunbeam.	.....do........	......
	12-cylinder V........	...do......	...do......	225-horsepower Sunbeam.	.....do........	.03
	Radial Star........	...do......	...do......	Salmson..........	Walker, 1912..	.054
Air-cooled fixed cylinder.	8-cylinder V........	...do......	Cast iron..	Renault..........	.....do........	.045
	Radial Star........	...do......	...do......	British Anzani....	Maker, Av. of 6.	.164
Air-cooled rotating cylinder.	1 Radial Star.......	Steel......	Steel......	8-horsepower German Gnome.	Maker.........	.167
	2 Radial Star.......	...do......	...do......	160-horsepower German Gnome.	.....do........	.167
Water-cooled fixed cylinder.	4 cylinders in line..	Cast iron..	Cast iron..	71-horsepower Daimler.	B.............	.047
	6 cylinders in line..	...do......	...do......	100-horsepower Argus.	....	.067
	8-cylinder V........	...do......	..do......	Curtiss..........	Maker.........	.045
			Steel......	Wolseley..........	Walker, 1912..	.041
Air-cooled fixed cylinder.	Radial star........	...do......	Cast iron..	Anzani..........	Lumet.........	.255
Air-cooled rotating cylinder.	1 Radial Star.......	Steel......	...do......	100-horsepower German Gnome.	Maker.........	.171
	2 Radial Star.......	...do......	...do......	200-horsepower German Gnome.	.....do........	.171
Water-cooled fixed cylinder.	4 cylinders in line..	Cast iron..	Cast iron..	100-horsepower Daimler.	B.............	.040
	6 cylinders in line..	...do......	...do......	100-horsepower Mulag.	....	.021
	8 cylinder V........	...do......	...do......	Hall-Scott.........	Clark, 1912....	.106
Air-cooled rotating cylinder.	1 Radial Star.......	Steel......	Steel......	1911-Gnome.......	Lumet.........	.212
Water-cooled fixed cylinder.	4 cylinders in line..	Cast iron..	Cast iron..	70-horsepower Daimler.	B.............	.031
	6 cylinders in line..	...do......	...do......	90-horsepower Schroeder.	....	.047
Air-cooled rotating cylinder.	1 Radial Star.......	Steel......	Steel......	1911 Gnome.......	Lumet.........	.253
Water-cooled fixed cylinder.	4 cylinders in line..	Cast iron..	Cast iron..	60-horsepower Daimler.	B.............	.029
	6 cylinders in line..	...do......	...do......	125-horsepower Hall-Scott.	Maker.........	.030
Air-cooled rotating cylinder.	1 Radial Star.......	Steel......	Steel......	1913 Gnome.......	Lumet.........	.255
Water-cooled fixed cylinder.	4 cylinders in line..	Cast iron..	Cast iron..	66-horsepower Benz.	B.............	.060
	6 cylinders in line..	...do......	...do......	87-horsepower Benz.	Maker.........	.022
Air-cooled rotating cylinder.	1 Radial Star.......	Steel......	Steel......	Gyro, 1911.........	Clark.........	.017

TABLE VIII.—*Oil consumption versus engine type and cylinder piston materials*—Continued.

Cylinders and cooling.	Class construction.	Materials.		Engine name.	Authority.	Oil per HP.-H.
		Cylinder.	Piston.			
Water-cooled fixed cylinder.	4 cylinders in line..	Cast-iron..	Cast iron..	100-horsepower N. A. G.	B............	0.038
	6 cylinders in line..	...do......	...do......	100-horsepower Cheno.	Clark.........	.005
Water-cooled fixed cylinder.	4 cylinders in line..	...do......	...do......	95-horsepower N. A. G.	B............	.009
Water-cooled fixed cylinder.	4 cylinders in line..	...do......	...do......	96-horsepower Argus.	B............	.089
Water-cooled fixed cylinder.	8-cylinder V.......	Cast iron..	Steel......	1911 Labor-Aviation.	Lumet........	.073
	12-cylinder V......	...do......	...do......	1911 Aviatic.......	.....do........	.054
	Radial Star........	...do......	...do......	Green.............	Clark.........	.11

There appears to be some relation between oil consumption and cylinder arrangement, but not so with reference to piston versus cylinder materials. For example, radial cylinders seem to require much more oil than vertical cylinders, but there is no conclusive evidence that air-cooled cylinders require more than those that are water cooled. Again, comparing the three Daimler engines as to oil versus materials, it appears that there is no appreciable difference between cast iron and steel cylinders, cast iron and steel pistons, though such a serious conclusion should not finally rest upon a single instance like this.

An effort to retain the low metal weight characteristics of steel and to meet lubrication requirements, that is worthy of note, involves the use of liners for cylinders and of sleeves, or even a separate barrel for pistons, made of a material such as cast iron or bronze having a good lubricating surface. This is not only objectionable as complicating the thermal and total stresses, increasing thermal resistance of cylinders, and adding something to weight removed but it now seems to be unnecessary.

At present the standard material for fixed cylinders is unquestionably cast iron with heads in one piece, and with cast-iron pistons. There is, however, a growing tendency to use tube steel for cylinders. This steel cylinder involves a head complication in shop practice, solution of which is now in course of development. Heads must have irregular forms due to ports and valve stem guides, which are most easily and satisfactorily cast. Such a cast head requires a joint to connect it to a drawn-steel cylinder. As alternatives the following are used, cast-steel cylinders with heads in one piece and cylinder and head machined from a forged billet or finally the complete sheet metal welded Daimler construction.

Steel is the adopted standard material for connecting rods and crank shafts and always is a very high tension alloy such as nickel or chrome nickel, which permits these parts to be very small and

light while amply strong and stiff. Crank case or frame material is still unsettled, ranging from the forged steel cage of the rotating cylinder engine through cast steel, cast iron, and aluminum, with the last prevailing in fixed cylinder engines. No successful attempt is yet on record, to use welded or riveted sheets and standard structural steel shapes in the long frames and crank cases of fixed cylinder multicrank engines, where frame weight per cylinder is a matter of considerable importance. It would seem as if stiffness or its equivalent uniformity of distortion can better be served with less weight by such structural steel construction than by the soft aluminum casting. To give a general survey of the practice in materials, Table IX is added.

TABLE IX.—*Materials*

Engine or makers' name.	Cylinder and crank arrangement rotating part.	Cooling medium and system.	Horse-power.	Number of cylinders.	R. p. m.
Benz	Vertical fixed separate	Water, C. P.	88 108 150	6	1,250 1,250 1,250
Hall-Scott	do	do	125	6	1,300
Frederickson, 2-cycle	Cylinders, rotating shaft, stationary.	Air		5 10	
Sturtevant	V-type, L head, cast in pairs	Water, C. P.	140	8	2,000
Sunbeam	V-type, L head, en bloc	do	150 225	8 12	2,000
Austro-Daimler	Vertical fixed separate	do	90 120	6 6	1,300 1,200
Le Rhone	Rotating cylinders, shaft stationary.	Air	80 160	9 18	1,200 1,150
British Anzani	Fixed star	do	25-200	3-20	1,250
Ransenzerger	V-type, separate cylinders, valves in head.	Water	150	12	1,200
Argyll	Vertical fixed, sleeve valves, separate cylinders.	do	120	6	
Wright	Vertical fixed, separate cylinders, heads screwed in.	Water, C. P.	60	6	1,400
Sturtevant	Vertical fixed cylinders en bloc, T head, 4 valves per cylinder.	Water	100	4	2,000
Curtiss	V-type, separate cylinders, L head, 4 valves per cylinder.	do	200	8	1,500
Chenu	Vertical fixed cylinders in pairs, T head.	do	65 90 100 850	4 4 6 6	1,800 2,300 1,600 1,500
Clerget	V or vertical fixed separate cylinders, valves in head.	do	50 100 200	4 4 8	1,450 1,300 1,300
Do	Rotary cylinders, valves in head, mechanically operated.	Air	50 80	7 7	1,180 1,180
De Dion Bouton	V-type, separate cylinders, L head	do	80	8	1,800
Edelweiss	Radial star, fixed pistons, reciprocating cylinders.	do	75 125	6 10	1,350 1,350
Laviator	V-type, separate cylinders, valves in head.	Water	80 120	8 8	1,200 1,700
Panhard-Levassor	V-type, cylinders en bloc, L head	do	100	8	1,500
Salmson	Fixed star, valves in head	do	90 135 200 300	7 9 14 9	1,250 1,250 1,250 1,200
Wolseley	V-type separate cylinders, valves in head.	Combination water.	82 130	8 8	1,650 1,200
Green	Vertical fixed, separate cylinders, valves in head.	Water	100	6	

NOTE.—I=integral head; C. P.=centrifugal pump.

for engine parts.

Materials for—									
Cylinder.	Cylinder heads.	Cylinder jackets.	Head jackets.	Pistons.	Valves.	Connecting rods.	Crank shafts.	Frames or crank case.	
								Upper.	Lower.
Cast iron..	I	Sheet steel, welded.	Sheet steel, welded.						
...do	I	I	I	Cast iron.	Tungsten steel.	I-section chrome nickel steel.	Chrome vanadium steel.	Aluminum alloy	Aluminum alloy.
...do	I			...do	Cast iron, rotary rocking.	Nickel steel.	Nickel steel.	Cast iron with nickel-steel rings shrunk over.	
...do	Cast iron..	I		Semisteel.	Tungsten	H-section chrome nickel steel.	Chrome nickel steel.	Aluminum alloy.	
...do	I	I	I	Steel		H-section high tensile steel.	High tensile steel.	Do.	
..do	I	Copper electrol dep.	Copper electrol dep.	Pressed steel.					
Steel with cast-iron liner.	I			Steel					
Cast iron..	I			Cast iron.	Nickel steel.	I-section nickel steel.	Nickel chrome steel.	Do.	
...do	I	Spun copper pressed on and locked by steel rings.		...do		H-section nickel steel.	Chrome vanadium steel.	Do.	
Forged steel.		Sheet steel, welded.							
Cast iron..	Cast iron..	I	I	Cast iron.	Valve heads, cast iron.	H-section chrome nickel steel.	Chrome nickel steel.	Do.	
...do	I	I	I	Semisteel.					
...do	I	Monel metal, welded.	Monel metal, welded.		Tungsten steel.	I-section.	Krupp steel.	Do.	
..do	I	I	I					Do.	
Steel	I	Copper electrol deposited.							
Forged steel.								Steel.	
Steel				Steel				Aluminum alloy.	
High tensile steel.				Cast iron.				Special aluminum frame.	
Steel	Air cooled.				Concentric valves, nickel steel.				
Cast iron..	I	I	I						
Forged steel.	I	Spun copper, corrugated, brazed.		Cast iron.		H-section.		Aluminum alloy.	
..do	I	Copper..	Steel exhaust-valve boxes.	Forged steel and phosphor-bronze bearing rings.		Tubular		Do.	
Cast steel..		Spun copper.	I	Cast iron.	Nickel chrome steel.	Nickel chrome steel.	Chrome vanadium steel.	Do.	

Form of cylinder proper including head is a direct contributing factor in the cylinder weight per horsepower, as is also to some extent the proportions. For a given bore and stroke, and made of the same material, all cylinders would weigh the same if they were similar in form, and as they are not similar the differences in form must account in some measure for total weight differences. That form that gives the least metal volumes evidently should be lightest. On this basis air-cooled cylinders with their radiating heat dissipating ribs, casings and baffles are heavier than water-cooled cylinders of the same bore, stroke, material, and similar valves. This excess weight of the air over the water-cooled cylinder added to its fan weight, when subtracted from the weight of radiator, pipes, pumps, and water, measures the excess weight of the water-cooled cylinder with its accessories. With radiators especially designed for lightness and for a minimum supply of water rapidly circulating, there is no essential reason why the air-cooled cylinder engine complete should weigh materially less than the water cooled. As a matter of fact, the actual difference itself is small, even when all contributing factors in each case are not equally well selected, as appears from the comparison of the weights of some well-known eight-cylinder V engines given in Table X.

TABLE X.—*Comparative weights per cubic foot displacement of air and water cooled 8-cylinder V engines.*

Engine or makers' name.	B. H. P.	R. P. M.	Bore (inches).	Stroke (inches).	Displacement (cubic foot per stroke).	Total weight, engine complete.	Engine weight per cubic foot per stroke.	Remarks.
Curtiss	75	1,100	4.00	5.00	0.2912	300	1,030	Water cooled. Water-cooled engines give weights without radiator water.
Curtiss	100	1,250	4.25	5.00	.3260	340	1,034	
Curtiss	160	1,100	5.00	7.00	.6370	700	1,100	
Sturtevant	140	2,000	4.00	5.5	.321	550	1,715	
Sunbeam	150	2,000	3.54	5.91	.271	610	2,245	
Sunbeam	225	2,000	3.54	5.91	.407	905	2,245	
Rausenberger	150	1,200	4.125	6.0	.557	590	1,060	
Clerget	200	1,300	5.512	6.299	.695	640	921	
Laviator	80	1,200	3.937	5.118	.289	275	952	
Laviator	120	1,200	4.488	6.299	.465	418	900	
Panhard-Levassor	100	1,500	4.331	5.512	.372	440	1,183	
Wolseley	130	1,200	5.0	7.0	.637	700	1,100	
De Dion-Bouton	80	1,800	4.173	4.724	.303	465	1,535	Air cooled. Weight given includes 2 exhaust connectors; also fan.
Renault	70	1,800	3.780	4.724	.233	396	1,700	Do.
Wolseley	82	1,650	3.750	5.500	.281	[1] 385	1,370	Cylinder barrels. Air cooled. Exhaust valves. Water cooled.

[1] Without flywheel.

NOTE.—Engine weights taken from Table I, where sources of information are given.

There is a somewhat surprising range of weights here and one that bears close study as directly related to design, form, and material quite independent of speeds and mean effective pressures. The lowest value is 900 and the highest 2,245 pounds per cubic foot of suction stroke. There seems to be no doubt of the superiority of head-valve construction over side-pocket valves in weight reduction, and there is no marked difference between an air and a water cooled

construction. This last conclusion is most important in view of the consistent inferiority of air cooling with reference to mean effective pressure and fuel consumption. Next to general arrangement, weights per cubic-foot displacement are fundamentally related to materials and wall thickness.

Cylinder metal volumes are least in any cylinder, other things being equal, when the valves are placed in the head instead of in side pockets, so in the interest of cylinder lightness this arrangement must be adopted unless it appears that the compensating factors, which will be referred to later, overbalance the extra pocket metal, but this is not the case. There are, however, several successful aero engines that follow the standard automobile practice of locating valves in side pockets mostly of the L-head form. One arrangement has the valves side by side, both stems pointing toward the crank case, both seating down in a wide pocket. The other locates the two valves axially in line, one stem pointing up, while the other points down, and seating on opposite sides of a narrow pocket.

The compensating weight elements referred to in connection with the head valve as compared with the side-pocket valve arrangement are those of valve gear. Two side by side valves in one wide pocket are ordinarily driven by a pair of push rods. Placing one valve above the other in a narrow pocket reduces the width and hence the metal of the pocket, but adds a rocker arm with bracket and pin and some additional rod length. Placing both valves in the head removes the pocket metal entirely, but adds a second rocker and push-rod extension ordinarily. It is the weight of these two rockers and push-rods extension that is to be balanced against the metal of the pocket. Such side pockets with ports, being irregular in shape and necessarily jacketed, can be formed, as in the case with cylinder heads that carry valves, only by casting (except when welded of sheet metal as in the Daimler experiment). The added cast iron due to pockets in combustion chamber and jacket wall will weigh more than the steel rocker arm and the push-rod extension. The weight difference in favor of the head-valve arrangement is greater still when a single rod alternately works in tension and compression on one rocker actuating both vlaves, as in the Austro Daimler, but in this case two different cams should be used, one to lift and the other to depress. Further reduction is possible in standard four and six cylinder engines by placing the cam shaft directly on the heads as in the German Daimler, for here the combined weight of all push rods is removed and the weight of a pair of gears and a vertical shaft introduced instead. This is no advantage, however, in V engines, because with the push-rod drive one cam shaft can serve both rods, and this is one of the advantages of V arrangement. Removal of one push rod and cam entirely becomes possible when the inlet valve is made automatic as it is in several engines, but the loss of volumetric efficiency resulting cuts more from the power than removal of push rod even with rocker does from the weight. For this reason automatic valves are not to be recommended, though there is another reason also strong enough alone, that of unrestrained seat impact.

Water-jacket metal in all cast cylinders will normally weigh more than the metal of the cylinder proper inclosed by it, in spite of the fact that it might be made thinner, due to lack of pressure loading in

one case and in the very high internal pressures in the other. The area of the jacket metal is considerably greater than that of the cylinder, especially when the water space is large, and the foundry can not make a sound jacket casting as thin as lack of stress would warrant. Accordingly, while the cast jacket is retained in many aero engines in accordance with automobile practice, this can hardly be accepted as the best aero engine practice, which seeks weight reduction by legitimate removal. Sheet metal of copper, brass, aluminum, or steel in sheets, in drawn tubes, spun and die pressed shapes is so peculiarly adapted to the purpose that its lack of immediate general adoption requires explanation. This is to be found first in the joint difficulty originally encountered in automobile practice, where such a mechanical discouragement was sufficient to cause rejection in view of the slight importance of the weight relation to automobiles, especially as the cast jacket is cheaper. With aero engines the case is different because the need of saving every ounce is vastly greater, and the cast jacket is a larger fraction of the total weight when all the other economics have been practiced, so the per cent gain by sheet metal substitution is great enough to warrant efforts to find suitable joints. This has been accomplished in a variety of ways, one of them being especially noteworthy, viz, electrolytic deposition of the whole jacket metal or electrolytic deposition of the joint. Added to this is the now generally available method of the oxygen flame weld, beside the usual screw-cover and press-fit joint which has always been available. Experience with these sheet-metal jackets has indicated the necessity for expansion provisions to avoid overstressing of the joint when the cylinder expands, exactly as in big gas engines. This conclusion is itself a measure of the distortional stresses set up in one-piece castings and an additional reason for their abandonment. To these advantages of weight reduction and relief of cylinder metal from jacket stress, the sheet metal jacket gives additional assurance of safety when jacket water freezes, and especially with cast heads or cylinders permits complete assurance of the external soundness of the cast metal that is to resist explosion pressures and of the reality of water spaces, which when cored may be filled with metal in corners where the designer intended water to be, so adding to expansion stresses and preignition tendencies that result from the consequential overheating.

At least three openings to the combustion chamber through the jacket space are necessary for insertion of inlet valves, exhaust valve, and igniter. The outer ends of these passages must be joined at the jacket wall by the jacket itself and the use of sheet-metal jackets calls for joints at these points. These offer no difficulty if welded autogenously or accomplished by electrolytic deposition, though considerable pressure joints are apt to be troublesome. Expansion is provided in three separate ways, (*a*) the slip joint, packed by a rubber ring as in Green (British), (*b*) corrugated bellows, (*c*) the elongation of a thin jacket of suitable metal provided the joint is welded as in the Benz (German) which seems quite satisfactory.

Jacket water spaces are usually made narrower on aero engines than others but the width may properly be even further reduced to hardly more than a water film as the corresponding high water velocity is beneficial to heat abstraction around the barrel. On the

heads greater width is usually necessary to avoid the formation of pockets where air or steam may collect next to the irregular port walls, and the outlet for water must be at the highest point to promote expulsion of any bubbles. Jacket lengths on the cylinder barrel are usually short, normally extending little if any below the lowest position of the piston head. This is not as satisfactory as a longer jacket even if the space be narrow, especially as the cylinder walls are so thin as to have a minimum of heat-conducting capacity longitudinally. The piston barrel will give heat to every part of the cylinder wall with which it comes in contact and if at some low part there is no water, then the heat must be dissipated to the air directly or conducted up to where the jacket starts.

Provisions for valve insertion and removal, to facilitate inspection and regrinding, are used in the very best large internal-combustion engine practice but would add weight to the aero engine if adopted. Inlet valves are carried in cages, which, with their fastening and the necessary additional guide walls, add several times the weight of the valve. Through the opening of the removed inlet cage the exhaust valve, which must seat on water-cooled metal, becomes accessible. This accessibility of valves is the primary recommendation for the side pocket, which permits of the use of the above construction when both stems are opposed in line as in the Mulag. In the parallel construction it is accomplished by two covers, one over each valve, as in Sturtevant. It is also attained in the head valve arrangement without cages by the separate or removable head which in aero engines is objectionable for many reasons. This problem has been boldly met by the designers of many of the best aero engines by simply providing a joint between cylinder and frame that is easy to loosen and by using valve gear and pipe connections that are quickly detachable, so the entire cylinder, which even in the largest sizes is not heavy, can be bodily removed by hand with ease and the valves reached through the bore. In this way the number of parts is kept to a minimum and a material contribution to low cylinder weight is secured.

Low valve weight would demand the thinnest disk and stem and the shortest possible stem, but process considerations are in opposition to this conclusion, especially in exhaust valves where heat dissipation is opposed thereby. Practice oscillates between these two extremes, but the heavy construction of exhaust valves must be favored while the light is permissible on self-cooling inlets, unless it be regarded, as in marine and automobile practice, unwise to use two different valves in the interest of reduction of spares. It is otherwise perfectly feasible to make inlet valve disks thin with short stems of small diameter, and exhaust valves thick with large diameter stems, perhaps taper bored from the end toward the disk, and long enough in the guides to dispose of the heat. If a metal of high conductivity could be found otherwise suitable, then exhaust-valve thickness might be reduced. Keeping the weights now used for both valves, the excess desired in exhaust valves can be secured by reducing the inlets, though many good engines are amply well cared for in this respect. Valve material is invariably steel, forged to meet the requirements of inertia and impact shock at high speeds and of corrosion, especially in exhaust valves, and alloy steels seem better adapted than carbon steels for this purpose. Shock troubles of

broken stems, battered push rods, and worn seats would all disappear if some form of good rotary valve could be evolved, and this is a most attractive possibility with as yet no realization in sight, though the case is by no means hopeless.

A general comparison of water cooled cylinder weights with various constructions of jackets, valve location, and drives, per cubic foot of displacement per stroke, is given in Table 11 to show limiting effects of various structural details, but unfortunately in an inconclusive way for cylinders alone, as shafts and frames are included.

TABLE XI.—*Weights of engines per cubic foot displacement (per stroke) versus type construction of parts.*

Cylinders and cooling.	Class construction.	Cylinder material.	Valve location.	Suction valve, A. or M.	Name.	Bore.	Stroke.	Revolutions per minute.	Weight per cubic foot.
Water-cooled fixed cylinders	4 cylinders in line	Cast iron	Head	M	Bena	5.180	7.087	1,288	1,075
			Pocket	M	Sturtevant	4.5	6.0	2,000	778
	6 cylinders in line	....do	Head	M	Daimler	4.724	5.512	1,315	1,418
			Pocket	M	Mulag	4.331	6.693	1,346	1,536
		Steel	Head	M	Daimler	4.134	5.512	1,387	1,301
	8 cylinders, V	Cast iron	...do	M	Curtiss	4.00	5.0	1,100	1,030
			Pocket	M	Sturtevant	4.00	5.50	2,000	1,718
		Steel	Head	M	Laviator	3.937	5.118	1,200	952
	12 cylinders, V	Cast iron	Pocket	M	Sunbeam	3.54	5.91	2,000	2,226
		Steel	Head						
Air cooled:	Radial star	Cast iron	Pocket	A	Laviator	3.937	5.118	1,300	1,115
		Steel	Head	M	Salmson	4.724	5.512	1,250	947
Fixed cylinders	8 cylinders, V	....do	....do	M	Wolseley	3,750	5.500	1,650	[1] 1,370
			Pocket	M	De Dion Bouton	4.173	4.724	1,800	1,535
	12 cylinders, V	Cast iron	....do	M	Renault	3.780	5.512	1,800	1,511
	Radial star	....do	Head	A	Ansain	3.54	4.72		837
						3.54	5.12	1,250	806
						4.13	4.92		865
	Horizontal opposed cylinder		Pocket	M	Ashmusen	3.75	4.5	1,800	1,000
Rotating cylinders	1 radial star	Steel	Head	A	B. M. & F. W.	4.331	4.724	1,031	625
	2 radial star	....do	....do	A	German Gnome	4.33	4.72	1,200	536
						4.72	4.72	1,200	436
Water-cooled fixed cylinders:	4 cylinders in line	Cast iron	Head	M	Daimler	4.724	5.512	1,412	1,375
			Pocket	M	Chenu	4.331	5.118	1,800	1,468
	6 cylinders in line	....do	Head	M	Argus	4.921	5.118	1,370	1,394
			Pocket	M	Chenu	4.331	5.118	1,609	1,527
		Steel	Head	M	Green	5.512	5.984	1,250	885
	8 cylinders, V	Cast iron	....do	M	Curtiss	4.25	5.00	1,250	1,084
			Pocket	M	Sunbeam	3.54	5.91	2,000	2,245
		Steel	Head	M	Laviator	4.888	6.299	1,200	900
	12 cylinders, V	Cast iron	Pocket	M	Rausenberger	4.135	6.00	1,200	1,060

[1] With flywheel removed.

NOTE.—Engine weights taken from Table I where source of information is given.

TABLE XI.—*Weights of engines per cubic foot displacement (per stroke) versus type construction of parts*—Continued.

Cylinders and cooling.	Class construction.	Cylinder material.	Valve location.	Suction valve, A. or M.	Name.	Bore.	Stroke.	Revolutions per minute.	Weight per cubic foot.
Air cooled:									
Fixed cylinders	8 cylinders, V	Steel	Pocket	M	Renault	3.780	4.724	1,800	1,700
	Radial star	Cast iron	Head	A	Anzain	4.13	5.71	1,250	825
						4.53	6.10		811
						4.13	5.52		801
Rotating cylinders	1 radial star	Steel	do	A	Gyro	4.290	4.748		
	2 radial star	do	do	A	German Gnome	4.88	5.51	1,200	511
						4.88	5.91		461
Water-cooled fixed cylinders	4 cylinders in line	Cast iron	Head	M	Daimler	5.512	5.906	1,373	1,310
			Pocket	M	Chenu	4.331	5.118	2,300	1,491
	6 cylinders in line	do	Head	M	Schroler	4.882	6.299	1,252	1,010
			Pocket	M	Chenu	5.906	7.874	1,500	1,270
	8 cylinders, V	do	Head	M	Curtiss	5.00	7.00	1,100	1,100
			Pocket	M	Panhard Levasson	4.331	5.512	1,500	1,183
		Steel	Head	M	Wolseley	5.0	7.0	1,200	1,100
Air cooled:									
Fixed cylinders	Radial star	Cast iron	do	M	Edelweiss	4.528	4.724	1,350	1,052
						4.522	4.724	1,350	863
Rotating cylinders	1 radial star	Steel	do	A	Gnome	4.33	4.724	1,194	569
	2 radial star	do	do	M	Le Rhone	4.13	5.51	1,150	646
Water-cooled fixed cylinders	4 cylinders in line	Cast iron	Head	M	Daimler	4.724	5.512	1,343	1,500
	6 cylinders in line	do	do	M	Hall-Scott	5.	7.	1,300	1,132
Air cooled:									
Fixed cylinders	Radial star	do	do	2-cycle A.	Laviator	3.937	5.118	1,200	912
Rotating cylinders	1 radial star	Steel	do	A	Gnome	5.118	4.724	1.156	467
Water-cooled fixed cylinders	4 cylinders in line	Cast iron	Head	M	Daimler	4.331	5.512	1,396	1,564
	6 cylinders in line	do	do	M	Austro Daimler	4.72	5.51	1,300	1,060
Air-cooled rotating cylinders	1 radial star	Steel	do	A	German Gnome	4.33	4.72	1,200	612
						4.72	4.72		563
						4.80	5.51		534

Water-cooled fixed cylinders	4 cylinders in line	Cast iron	Head	M	Daimler	4.724	5.512	1,391	1,513
	6 cylinders in line	do	do	M	Austro Daimler	5.12	6.90	1,200	975
Air-cooled rotating cylinders	1 radial star	Steel	do	A	German Gnome	4.88	5.91	1,200	507
Water-cooled fixed cylinders	4 cylinders in line	Cast iron	Head	M	N. A. G.	5.315	6.294	1,344	1,265
	6 cylinders in line	do	do	M	Benz	4.17	5.91	1,250	1,261
Air-cooled rotating cylinders	1 radial star	Steel	do	A	Frederickson	4.50	4.75	....	680
Water-cooled fixed cylinders	4 cylinders in line	Cast iron	Head	M	N. A. G.	4.724	4.724	1,408	1,272
	6 cylinders in line	do	do	M	Wright	4.375	4.5	1,400	1,300
Air-cooled rotating cylinders	1 radial star	Steel	do	M	Le Rhone	4.13	5.51	1,200	691
Water-cooled fixed cylinders	4 cylinders in line	Cast iron	Head	M	Argus	5.512	5.512	1,368	1,205
Air-cooled rotating cylinders	1 radial star	Steel	do	M	Clerget	4.724	4.724	1,180	588
						4.724	5.906	1,180	513
Water-cooled fixed cylinders	4 cylinders in line	Cast iron	Head	M	Argus	4.921	5.118	1,342	1,385

Here, again, the superiority of the head over the pocket valve arrangement, and the indifference of air versus water cooling, are demonstrated, but in addition the steel cylinder is shown to be superior to the cast iron. As to arrangement of cylinders with reference to crank shaft, comparing the four and six in line, the 8 and 12 cylinder V, there is nothing conclusive demonstrated, though for the latter there are insufficient figures available. Radial star arrangements are consistently lighter than the above, not as much as might be expected for fixed cylinders, but quite markedly so for the rotating, which in round numbers weigh only half as much as the line arrangements. It is the consistent use of steel for cylinders in the rotating against the cast iron in the fixed star arrangements that is responsible for the weight differences reported rather than rotation versus fixity.

Cylinder weight must have some relation to the ratio of bore to stroke for equal displacements, and the variation of stroke per unit of displacement must affect as well the shaft and frame weights. The thickness of the cylinder walls should vary directly with the diameter for explosion pressure stress resistance, while displacement varies directly as the square of the diameter, and directly as stroke. The actual ratios of stroke to bore will be between one and two, the former giving a very short and the latter a very long stroke engine according to practice. The short-stroke cylinder will require a thicker wall than the long for stress resistance, but the difference is so small in view of shop limits and the small diameters that it can be neglected. Even allowing extra thickness, the short-stroke engine will be lighter than the long as to cylinder weight and doubly so when the increased thickness of crank and larger crank case necessary are included. More effect on weight reduction is possible by offsetting cylinders than by working to extremes of stroke bore ratio, as this reduces the height of engine, especially when the connecting rod is shortened as it may be at the same time to equalize the side thrust friction on the two sides of the cylinder wall. This offsetting is quite generally practiced, though it is by no means universal, and weight reduction possible by this means is small.

Cylinders when cast are cast sometimes singly, sometimes two, three, or even four together, to make up multicylinder engines, and this is a factor in weight reduction. Casting a single cylinder complete with head and cast jacket is the old standard practice for small stationary engines, and the method first adopted for auto engines. Such cylinders simplify and cheapen the construction of multicylinder engines of different numbers of cylinders to give different horsepower units, as the only change required to get a new capacity engine is in frame, cam shaft, and crank shaft. When automobile engines became standardized to the four cylinders in line, four crank form, it became evident that weight would be saved and compactness promoted by casting two cylinders in one piece, the jacket consisting of two semicylindrical and two tangent flat plate elements for the barrel, and two semicircular and one flat plate nearly square, connecting member for the top instead of two circles. This produced a stiff structure which permitted a reduction of frame or crank case stiffness, and it shortened the frame and shaft, but required the elimination of one main bearing between the cylinders, for which with this arrangement there is not sufficient room. As a partial offset there is required a somewhat thicker crank and shaft to com-

pensate for the increased bending moment that follows the spreading of main bearings as supports. This practice of casting two cylinders enbloc for four-cylinder engines is equally adapted for six, and is quite commonly adopted, though not universally. Aero-engine practice followed in part this auto and marine practice for cast cylinders of making two enbloc, so that the four-crank engine has three and the six-crank engine four main bearings.

Cylinder removal is facilitated by separate cylinder castings, because there are less parts to be detached, and the weight to be lifted is the least. Separately cast cylinders are better adapted to sheet-metal jackets, so aero engines departed from automobile two enbloc practice in casting such cylinders separately and leaving a bearing between each crank. The four crank engine then has five, the six crank, seven bearings, and the whole engine is symmetrical. This is perfectly sound and good practice, for there are no more important members than the crank shaft and the frame. By this construction the maximum stiffness and best distribution of main-bearing surface is secured, with least deflection at crank pins, and the extra shaft and frame length is worth the small cost in weight, for the weight increase is very small. Steel cylinders are always separate and can be substituted for the cast cylinders with sheet-metal jackets on this type of frame and shaft without any alteration whatever, as may also air-cooled cylinders, which by the very nature of the problem of air cooling can not be cast in pairs at all.

Frame form, for connecting cylinders and main bearings, has a very large influence on the weight per cylinder in multicylinder multicrank engines, because the more direct the stress resistance, the less the metal required. As evolved from old stationary and marine steam engine practice, the main bearings support the shaft from below, the caps being removable upward, which requires a two-part frame. The lower frame member consists of a cross web to carry each main bearing, and these are tied together by a longitudinal web just out of reach of the crank throw, so for a multicrank engine this lower frame member becomes essentially a semicylindrical box with a semicircular cross partition for each main bearing. The upper frame member ties the cylinders to this box by another box, or by the A form of double column. The latter receives a cylinder at its upper ring end, and its legs seat on the lower frame in the plane of the crank path. Thus the stress which is alternately tension and compression in standard steam engines, is communicated from cylinders to main bearings in a decidedly roundabout way. The same is true of the second or box form of upper frame member as to indirectness of stress transmission, for here the upward cylinder thrust is received by a flat plate with holes in it, one for each cylinder, and this horizontal flat plate transmits it down two inclined semi-vertical plates to the edges of the cylindrical box of the lower frame member, which carries the vertical main-bearing cross webs.

Single-acting internal-combustion engines are subjected to a frame stress from explosion-gas pressures; that is, a pure tension between cylinders and main bearings, although inertia of reciprocating parts at high speeds on idle strokes may introduce a compression equivalent to the double-acting steam engine. Aero engines are necessarily light and their parts also, so that there is no real necessity for bottom gravitational support of the crank shaft, nor for keeping the old

scheme of removal through end holes in box frames or sidewise through removable columns. Aero-engine crank shafts can perfectly well be supported below by bearing caps, removal of which permits the shaft to drop free. This greatly simplifies the frame which need not be more than a short cross web hanging between cylinders under a horizontal flat plate with holes for each cylinder. This cross web, if cast of aluminum, can be formed for compression resistance as a column, and steel tension rods inserted to relieve it entirely for the tension stress it can not resist. The substitution of steel shapes welded or riveted for the aluminum casting is perfectly feasible in such form as to equally well serve as struts and ties. Resistance of longitudinal bending of crank shaft due to the relative forces at two different cylinders or cranks, is easily resisted by side plates in the cast form, or by diagonal latticed braces in the structural form. This means the elimination of the old lower frame member entirely and the substitution for purposes of inclosure of a mere shell subjected to no stress whatever, but formed solely in the interest of an unstressed oil-tight inclosure.

Aero-engine frames have not all developed along these lines, practically all being of cast aluminum and only a few introducing the steel tension rod, Green for example, while a great many retain the bottom web, leaving a hole where the more serviceable upper direct web should be. There are no structural-steel frames. Reference is made to the illustration in the appendix to frame constructions which should be judged in this light. Modifications of frames along these lines will materially improve the stiffness and life of main bearings, which should reduce lubrication difficulties as well, for the same frame and shaft weights now used, or result in an equivalent weight reduction.

Main bearings are almost universally of the plain type lined with so-called antifriction or white metal, though in a few cases ball bearings, which seem ill adapted, have been employed. The thrust bearing, which is peculiar to aero as compared to auto engines, because the useful effect of all power developed lies in propeller thrust against the frame, must be suitably supported by the frame. As the loads are not severe, and the thrust not irregular as in main bearings, but reasonably steady and always in one direction, this offers no difficulty. The longitudinal side plates connecting the main bearing webs, to make the frame stiff as a beam, are equally serviceable in making it serve as a column loaded by propeller thrust, if the end plate be suitably stiffened. This end-plate stiffening is all the frame modification required to receive the thrust bearing.

Aero-engine pistons follow almost universally the practice in auto engines as to use of cast iron as a material, but vary in practically every other respect. They are invariably shorter and thinner, being machined all over as nearly as pin bosses permit, in an effort to reduce weight, which in many cases has been carried entirely too far. Unless normal speeds are made higher than at present, say 1,500 revolutions per minute, the piston weight can be considerably greater without developing inertia forces equal to explosion pressures. With present piston weights this equality between explosion pressure and inertia forces is reached about 2,500 revolutions per minute. In any case metal sufficient for heat conduction must be available, and

reduction on this basis becomes legitimate only when better thermal conductors than cast iron, such as aluminum, copper, or the bronzes, are substituted for it. Complete substitution is difficult, in view of their expansion coefficients and low stress resistances, but these materials can be used as supplementary conductors to stiff cast-iron piston frames. As piston-weights of any one design increase per square inch of piston, the use of a large number of small pistons results in legitimate piston weight reduction over a smaller number of larger ones of equal area. With the exception of the brass L section single top ring of the Gnome engine, aero-engine piston rings differ not at all from the cast-iron ring of auto engines. Usually the thin lower end of aero-engine pistons is stiffened by an internally projecting web, which is an excellent feature and should be retained, however heads and upper barrel are increased. Flat heads, being structurally weak and inflexible, should be definitely abandoned, as is also the case with any cast ribs on the under side of the head, especially as these are useless in tension and involve shrinkage stresses in the making. Downward curving or concave heads being in tension, must likewise yield to the convex upward or domed pistons such as the Daimler, which, without ribs, is the best possible form, but these would be much improved by thickening at the edges. Wrist-pin bosses, while in a few cases separately attached, are normally cast integral, a practice that leads to least metal for strength, though the deformation tendency on expansion is unfavorable.

As a partial compensation for the increased unit side thrust due to shortening of pistons and use of short connecting rods, there is a marked tendency to offset the cylinders an amount recommended by Vorreiter as one-eighth the stroke. This is of no assistance whatever when inertia forces are as high as they should be, as on the suction stroke a side thrust equal to that developed by gas pressure alone is imposed on the other side, so that the symmetrical cylinder setting in line with crank shaft should not be abandoned for this reason. The principal value of offsetting is reduction of engine height.

Wrist pins are properly made hollow in some cases to reduce weight, while leaving enough metal to resist undue stressing and securing the maximum bearing area for the rod end. They should always be hollow. The old bad practice of tapering pin ends is often retained, though in view of its natural tendency to work the pin toward the big end, to loosen and to score the cylinder, which tendency is only opposed by excessive locking requirements, should have been long ago abandoned. Plain cylindrical-ended pins, of two diameters but slightly different, is the best practice, and the next best is a straight pin or tube locked in the bosses. Bearings in the bosses with pins fixed in rod ends have never proved satisfactory in other engines, and there is no difference in aero engines that warrants a different conclusion.

Connecting rods follow the usual auto practice in having the wrist-pin end solid forged, bored, and bushed, with the old split-marine form of crank-pin end, lined with soft metal, and forged of steel. They are, however, universally of high tension alloy steel of sometimes tubular, but almost universally, I section. The special rod forms are confined to the rotating cylinder engines with many rods per crank, where each engine is characterized by some arrangement peculiar to itself, all involving, however, a single bearing embracing

the crank pin, to which the other rods are movably attached to allow the small relative oscillation of each with reference to this bearing. This system, which for the want of a better name, may be called the master-and-shoe rod-end construction, even though the name applies to only one form, is adapted to the double rod per crank construction of the V engine as a substitute for the separate embracement of the crank pin by each rod, either of similar rod ends side by side or one straight and the other forked, as the master and shoe results in lower mean pressures and less friction than the double direct.

Weight of engine proper per horsepower is, as pointed out, not to be secured by reducing engine metal alone or by raising speed alone, but may follow a raising of mean effective pressures without any change in metal or speed. It may also be secured with the same metal by maintaining mean effective pressures with increasing speed, or even by lessening mean effective pressures at increasing speeds, provided the latter increases faster than the former decreases. It is therefore important to return to the question of mean effective pressure and examine it in the light of such arrangements of engine as may affect the weight of cylinder complete per cubic foot of displacement and the weight of shaft and frame per cylinder. Mean effective pressure indicated is entirely a question of port and valve size and of port, valve, and combustion chamber temperatures. The former affects the weight of charge by pressure drop and the latter by suction-temperature rise, but the latter also limits the compression, which is the other factor in mean effective pressure. Mean effective pressures referred to brake horsepower are the same, except for mechanical friction and in the case of two-cycle engines for pump work. Any alternative arrangements or detail form that do not inherently increase the suction-pressure drop or the suction-temperature rise or do not produce hotter internal combustion-chamber walls may be made to yield equally high mean effective pressures by the use of suitable proportions and dimensions of passages and chambers. Forms or arrangements of this sort that reduce engine weight per cubic foot also directly contribute to the desired result of reduction of weight per horsepower.

According to this, a given number of fixed water-cooled cylinders of the same size should yield the same indicated mean effective pressures, no matter how they are arranged, whether, for example, four are radial or in line, six in the radial groups of three each or all in line, eight in line or in two fours V connected. Any differences actually found must be charged to proportions, to carburation, or to ignition, and can not be regarded as inherently characteristic of the grouping, though, of course, mean effective pressures referred to brake horsepower will differ by the difference in mechanical friction, which is least for the least product of bearing surface and mean bearing pressure. The same is not true for fixed air-cooled cylinders because their form and arrangement does, to an appreciable extent, affect their temperatures, though the suction-pressure-drop effects can be made the same for all. Therefore, more differences may be justifiably expected among fixed air-cooled than among fixed water-cooled cylinders.

The fixed air-cooled cylinders are likely to run hotter than the water-cooled cylinders so their mean pressures would be lower, as much so as the cooling is ineffective.

Rotating air-cooled cylinders taking their charge through the pistons, probably suffer the greatest of all suction heating effects and must be expected to have the lowest mean effective pressures, indicated and brake, more so because the windage is added to mechanical friction.

Automatic suction valves whether used in fixed cylinders or in the pistons of rotating cylinders, must always oppose suction by greater pressure drops than mechanical valves, each suitably designed, so such engines should have lower mean effective pressures.

Thick-walled cylinders and thin-walled pistons should run hotter than thin cylinders and thick pistons, so differences in mean effective pressure may be expected in these directions, always subject to proper selection of proportions in other directions.

Speed limits should inherently be the same for all fixed cylinder engines, no matter how disposed, so that with proper proportions there is no reason why any arrangement should suffer a greater falling off in mean effective pressure with speed increase than any other, however much the constant high value for one may differ from that of another. Rotating cylinder engines are, however, subject to lower speed limits than are fixed cylinder machines, on account of centrifugal forces, though there is no reason why one kind of rotating cylinder engine should not run as fast as another, nor why all should not suffer the same rate of decrease in mean effective pressures with speed increase, as do fixed cylinder engines except as windage may cause greater losses, referred to brake horsepower.

Any one type of cylinder and piston will run hotter the larger its diameter, so a given piston area in a large number of cylinders should result in higher mean effective pressures from the reduction of suction heating and the increased compression made possible by the cooler interiors. Therefore an eight-cylinder V should be better than four or six cylinders in line of equal displacement, and the rotating cylinder engine of several rows and cranks should be better than equal displacement in one row and one crank.

Similarly a large stroke bore ratio, favoring smaller piston diameters for equal displacements, should yield higher mean effective pressures than a small ratio but this difference is necessarily small, as reduction of cylinder diameter from 6 to 5½ inches, for example, can not greatly affect interior temperatures.

These principles should all be checked by experimental data and can be so checked, but such data have never yet been obtained, largely, because such tests as have been made were directed toward a comparative judging of engines in competition, and were not conducted for discovery of principles of construction. Such results as are available are compared in Table 12 with reference to the variables discussed. In the same table are incorporated the figures for thermal efficiency which controls the weight of fuel to be carried. This, while slightly affected by valve resistances as is mean effective pressure, is dependent primarily on compression for indicated efficiency, and on engine friction and negative work for brake efficiency. It therefore is most affected by temperatures of the charge before compression starts and by interior temperatures, as these affect the maximum compression. As might be expected therefore the differences between the thermal efficiencies are less than those between mean effective pressures.

TABLE XII.—*Mean effective pressure and thermal efficiencies versus type construction of parts.*

Cylinders and cooling.	Class construction.	Cylinder material.	Valve location.	Suction valve A. M.	Name.	Bore.	Stroke.	Revolutions per minute.	Mean effective pressure.	Efficiency.
Water-cooled fixed cylinders	4 cylinders in line	Cast iron	Head	M	Benz	5.180	7.087	1,288	106.9	0.29
	6 cylinders in line	do.	do.	M	Daimler	4.724	5.512	1,315	107	.26
			Pocket	M	Mulag	4.331	6.693	1,346	101.3	.26
		Steel	Head	M	Daimler	4.134	5.512	1,387	114.4	.27
	8 cylinders, V	Cast iron	do.	M	Curtiss	4	5	1,100	107.7	.22
			Pocket	M	Sturtevant	4	5.5	2,000	100.3	.24
	12 cylinders, V	do.	do.	M	Sunbeam	3.54	5.91	2,000	126.8	.25
Air cooled:										
Fixed cylinders	Radial star	do.	Head	A	Anzani	3.54	4.72	1,250	76.2	.23
						3.54	5.12		78.5	.24
						4.13	4.92		76.9	.24
Rotating cylinders	1 radial star	Steel	do.	A	B. M. & F. W.	4.331	4.724	1,031	66.6	.16
	2 radial star	do.	do.	A	German Gnome	4.33	4.72	1,200	67.9	.21
						4.72	4.72		67.2	
Water-cooled fixed cylinders	4 cylinders in line	Cast iron	Head	M	Daimler	4.724	5.512	1,412	103.5	0.27
	6 cylinders in line	do.	do.	M	Argus	4.921	5.118	1,370	101.1	.23
	8 cylinders, V	do.	do.	M	Curtiss	4.25	5	1,250	111.7	.25
			Pocket	M	Sunbeam	3.54	5.91	2,000	126.5	.25
Air cooled:										
Fixed cylinders	Radial star	do.	Head	A	Anzani	4.13	5.71	1,250	83.2	.27
						4.53	6.10		80.1	.25
						4.13	5.52		86.2	.26
Rotating cylinders	1 radial star	Steel	do.				4.748	954	76.9	.17
	2 radial star	do.	do.				5.51	1,200	78.7	.21
							5.91		65.2	
Water-cooled fixed cylinders	4 cylinders in line	Cast iron	Head	M	Daimler	5.512	5.906	1,373	102	0.28
	6 cylinders in line	do.	do.	M	Schröber	4.882	6.299	1,252	79.2	.22
	8 cylinders, V	do.	do.	M	Curtiss	5	7	1,100	104.7	.24
Air cooled rotating cylinders	1 radial star	Steel	do.	A	Gnome	4.331	4.724	1,194	75	.17

Water-cooled fixed cylinders	4 cylinders in line	Cast iron	Head	M	Daimler	4.724	5.512	1,343	107.1	0.27
	6 cylinders in line	do	do	M	Hall Scott	5	7	1,300	92.75	.21
Air-cooled rotating cylinders	1 radial star	Steel	do	A	Gnome	5.118	4.724	1,156	71.3	.17
Water-cooled fixed cylinders	4 cylinders in line	Cast iron	Head	M	Daimler	4.381	5.512	1,396	102.8	0.27
	6 cylinders in line	do	do	M	Austro-Daimler	4.72	5.51	1,300	94	.26
						4.33	4.72	1,200	67.9	
Air-cooled rotating cylinders	1 radial star	Steel	do	A	German Gnome	4.72	4.72	1,200	67.2	.21
						4.88	5.51	1,200	78.7	
Water-cooled fixed cylinders	4 cylinders in line	Cast iron	Head	M	Daimler	4.724	5.512	1,394	93	0.27
	6 cylinders in line	do	do	M	Austro-Daimler	5.12	6.89	1,200	93	.26
Air-cooled rotating cylinders	1 radial star	Steel	do	A	German Gnome	4.88	5.91	1,200	65.2	.21
Water-cooled fixed cylinders	4 cylinders in line	Cast iron	Head	M	N. A. G.	5.315	6.299	1,344	101	0.28
	6 cylinders in line	do	do	M	Benz	4.17	5.91	1,250	113.5	....
Air-cooled rotating cylinders	1 radial star	Steel	do	M	L. C. Rhone	4.13	5.51	1,200	85.6	....
Water-cooled fixed cylinders	4 cylinders in line	Cast iron	Head	M	N. A. G.	4.724	4.724	1,408	94.9	0.26
	6 cylinders in line	do	do	M	Wright	4.375	4.5	1,400	83.7	.23
Water-cooled fixed cylinders	4 cylinders in line	Cast iron	Head	M	Argus	5.512	5.512	1,368	106.5	0.26
Water-cooled fixed cylinders	4 cylinders in line	Cast iron	Head	M	Argus	4.921	5.118	1,342	107	0.23

NOTE.—Values for mean effective pressure taken from Table IV, where source of information is given. Efficiencies calculated from fuel consumption values in Table V, where authorities will be found.

There appears to be no consistent difference between the performance characteristics of steel compared with cast iron, as combustion chamber materials, when measured in terms of mean effective pressures or thermal efficiencies. The same is true, as might be expected, for fixed cylinder-crank shaft arrangements of four or six in line compared with 8 or 12 cylinder V, or star, though the figures for the latter do fall off a little. As indicated before, the fundamental difference is in air versus water cooling, and fixed versus rotating, or crank case versus direct admission of charge. Fixed cylinders are always superior to rotating, other things being equal, direct charge admission to crank case admission, and water cooling to air cooling.

Reliability of the engine as affected by arrangement, form, proportions, and materials is partly a process question and partly one of endurance of structure. So long as the mixture is made regularly and properly received into the cylinders, and then treated always the same, which includes ignition and cooling, then the mean effective pressure and thermal efficiency should remain the same, and the engine continue to run indefinitely. This is the process part of reliability. It is equally necessary, however, that no part shall break or fastenings loosen, and that bearings shall neither seize nor wear too fast or unevenly. Breakage means immediate involuntary stoppage, and loosening or bearing trouble a more or less fast approach to a stoppage, which, if anticipated, may be voluntary, or if not, a stoppage essentially the same in immediate effects as a breakage.

There is no excuse to-day for any greater number of breakages of aero engine parts than of similar parts of other engines, provided the same amount of skill and foresight in design and construction are exercised. The fact that the consequences of breakage are so much more serious in the case of the aero engine than in any other is sufficient reason why the breakages should be even less than on any other, and should not exceed those that could be called pure accidents beyond the utmost skill and care. It is, however, undoubtedly a fact that stress analysis, skill, and material data, for operating conditions, are far less generally applied to aero engine design than to other important classes of machinery. This is partly because the youth of the art has kept the inventor in the foreground and the computer behind, but largely through lack of rigidity of requirements by purchasers and lack of financial support of the business. If the business of aero engine production were large and regular, or Government supported, it could not only afford to pay experienced stress analysts, metallurgists, and material investigators, but would be forced to do so.

Breakage prevention is therefore almost entirely a question of money, and of realization that design is not purely invention. It is, however, somewhat a question of arrangement and form, for, as has been mentioned, from time to time some arrangements or forms lend themselves better to design for assurance against breakage than do others, or some promote a reduction of seriousness of the consequences of breakage, if it does occur, through pure accident. An illustration of this latter point is the case of the rotating cylinder arrangement versus the fixed. Breakage of a cylinder fastening means a throwing off of the mass under the influence, not merely of the gas pressure but of centrifugal force as well, and with a good possibility of much more serious consequences for the former. Even the breakage of one of the radial valve tappet rods will cause a loose end to fly out and whip

through the supporting structure. Such is believed to have been the cause of wrecking a British machine in flight and causing the death of the two passengers. Partial ruptures such as cracks in piston and cylinder are preventable by proper cooling, but the substitution of steel for cylinders directly contributes to this result, as does arching of pistons, the former a contribution of materials and the latter one of form to structural permanence. Complete ruptures are probably more common in valve stems and other small parts than in the main elements of frame, shaft, cylinder, piston, and rods, indicating lack of care or insufficient experience.

All such things are to be eliminated by organization, supplemented by time and by long periods of operation of experimental engines, run under specified unfavorable conditions to complete destruction of any one part under investigation, such as a valve and stem, or of the whole structure. Testing to destruction is the very best way to accelerate experience without danger to anyone. As in the case of the other illustration cited, however, form can contribute something to the reduction of consequences of breakage, and in the case of the stem of the head valve, this has been attempted by placing the edge of the valve seat slightly over one side of the cylinder bore in an offset, or complete enlargement of diameter at the clearance and with the valve circle tangent to the bore. Should a stem break, the valve will drop to the cylinder shoulder instead of on top of the piston, which smashes it or itself, provided the break is high enough upon the stem so the stem does not emerge from the guide. Otherwise the result is quite the same as if the shoulder were not present, except that a larger diameter of valve is possible than without such extension of the bore. This valve trouble is supposed to be quite prevented by side-pocket location of valves, but is not, because should the valve drop into the pocket there is every chance of it sliding over on the piston under the influence of a suction stroke, especially if the flat bridge inclines downhill, as it usually does in single cam shaft V engines, for example, though placing the valve on the opposite or downhill side would prevent it, but would require two cam shafts.

Prevention of undue wear on shaft and pin bearing surfaces is entirely a question of bearing pressures and lubrication. These bearing pressures are all subject to pretty accurate determination by computation, so the design of an engine with excessively high bearing pressures, judged by general machinery bearing experience, is a pure technical mistake, not to be excused by the addition of elaborate forced systems of pump oil supply. Bearings should be large enough to not need elaborate special oils or oil-application systems, but these should be added to make assurance doubly sure, in short; as safety attachments, not as essential elements. Weight reduction secured by cutting down main and pin bearings is too dearly bought to be worth the price. Cylinder and piston bearing wear, while involving the same elements as main bearings, have to endure the additional difficulty of high temperature, but this is not serious if due attention is paid to the principles of heat abstraction. Violation of these principles, coupled with a rise of side thrusts, aggravated by side cocking that follows undue shortening of pistons, is another case of pure neglect. Pistons should be as long and as thick at the top as is consistent with weight-speed limits, and where observance of these limits fails to reduce the pressures and temperatures to values known

to run properly in other engines, then definite special remedies can be suggested, only one of which is excessive use of lubricating oil and the last to be adopted instead of the first.

Seizing of running parts at bearing surfaces is entirely a question of relative size or of clearances, and its prevention a question of maintenance of the cold clearances after the parts become heated, which, of course, is least necessary, the better the provision for abstracting and dissipating the heat derived from combustion or developed by friction. Next to cooling, which in main and crank pin bearings is not attempted, though it might well be, and which in cylinders and pistons is their big problem, material selection is most important. Some materials have low relative frictional coefficients for their lubricated surface and are properly related as to thermal expansion. Nothing better than the soft-metal lined or bronze can be found for steel shafts and pins, especially as these expand more per degree rise than the steel, so heating tends to loosen and oppose seizing by assisting lubrication, which by lowered oil viscosity tends to become less effective. The boxes must, however, be stiff enough to really distribute stress. Piston and cylinder bearing surfaces are somewhat more difficult, as the outer part, the cylinder, is normally much cooler than the inner part, the piston. The temperature difference is greater the thinner the pistons, and the difference is much greater than in the case of the standard box on the pin or shaft. It is, therefore, more necessary to care for these clearances. This is done when the materials are the same, cast iron on cast iron, by making the initial clearance high, far higher than would be feasible on shafts. This tends to promote side knocks and leaks at part load. For equally good cooling the steel cylinder with cast-iron piston gives about the same expansion relations as do the bronze box and steel shaft, but not such good antifriction qualities. Steel selection and heat treatment will undoubtedly lead to improved antifrictional results, perhaps even equal or superior to cast iron, after proper research. This seems to be a rational and promising line of development, especially if the cylinders are kept symmetrical, as they can be with head valves.

Reliability so far as carburation, ignition, mixture distribution, and cylinder treatment processes are concerned, has already been discussed. Any derangement whatever here leads to impaired power output or increased and perhaps very much increased fuel consumption. Serious derangement of these processes means stoppage even though the whole engine structure be perfect. Most operating troubles are directly traceable to these process derangements, which if sufficient in degree, mean stoppage, and even if slight, constant tinkering and anxiety.

Adaptability of an internal-combustion engine to aeronautic service is promoted by certain features of the engine that play no part in metal reduction, in mean effective pressure and efficiency increases or in its reliability, though of course low weight of engine and of fuel per horsepower are themselves adaptability factors, as is also any element of reliability.

General external shape and position of points of attachment are subject to a far wider range in aero than in auto engines. In one respect aero adaptability imposes a direct requirement, that of end shape for least head resistance. Engines directly exposed to the air or their casings when covered have a relative movement always

approaching, and sometimes exceeding, 100 miles per hour. This must always impose a resistance which is larger, the larger the end area facing the direction of flight and the less smooth the exposed surfaces are. In this respect the rotating-cylinder engines are by far the worst and the single line of cylinders of the auto type of multi-crank engine is best, nearly twice as good as the V engine for example. Air-cooled engines if similarly arranged to water cooled offer more head resistance except for the radiator of the latter which may be very highly resistant but is not necessarily so. But apparently the requirements of low head resistance is losing in importance, at least for war machines, since in these the fuselage is roomy enough generally to accommodate any type of engine.

Ease of starting and a control of speed are also required of aero as of automobile and boat engines, but with some elements of difference. Electric self-starters with generator-motor and storage batteries are prohibited by weight limits, for even if the craft could carry them their weight would be much better disposed in the engine by adding either more horsepower of the same unit weight, more fuel for the same engine to make longer flights, or for equal flights and engine power by using a heavier built and therefore less sensitive engine of longer life. When starting from the ground a starting crank on the shaft end often would be inaccessible and even if it were within reach, engines of large power could not be hand rotated against their normal compression. It has been a general practice to start these engines by hand turning of the propeller blades, a practice that is most dangerous, does the blades no good and certainly requires an extra man because at the moment of starting the operator must be in his seat. All hand-starting difficulties are removed if the compression is relieved and the accessibility of a starting crank can be met with equal ease by a chain and sprocket having a self-releasing ratchet and hand crank on a short auxiliary shaft, near the operator's seat. It may therefore be regarded as necessary that aero engines, certainly the larger ones, and this means most of all if not all of those to be built in the near future, be provided with compression-release cams, equivalent to those so long used on hand-started stationary engines and lever operated from the seat. This same compression release gear will serve as a speed control, should speed variation be necessary, by permitting escape of part of the charge though, of course, with waste of gasoline. It serves as a supplement to the throttle valve of the carbureta, and which is not so wasteful of fuel. Speed reduction by spark retardation should not be practiced on aero engines, though a starting retard is necessary, automatic or manual, because of the serious overheating effects that follow, and aero engines at best are hard enough to keep cool at their high speeds.

Muffling may be regarded as a necessity, however much free exhausts have been used in the past, and whatever unfavorable weight and power effects are imposed must be regarded as warranted. Noise from the exhausts of so many cylinders operating at high speeds becomes a loud roar. There are at 1,200 revolutions per minute from the 20 cylinders of the Le Rhone engine, for example, $600 \times 20 = 12,000$ air impacts per minute, and at 2,400 revolutions per minute the eight cylinders of the Sunbeam engine give $1,200 \times 8 = 9,600$ impacts. With such a disturbance close to him no operator can be expected to keep his head as clear for the serious business of

flying as if the noise were absent. To detect engine defects by the noise changes in the machine before they become serious is absolutely impossible, though this is the main reliance in operating any other kind of machine. Free exhausts must be classed, therefore, not as annoyances but as preventers of engine-trouble detection, no matter what the type of machine, and for military machines they are the finest kind of approach signal to the enemy, being audible long before the machine is visible.

Mufflers can be made, due to automobile development, that are quite effective with no more than 2 pounds per square inch back pressure, and possibly less. This will reduce engine output 2 per cent if the mean effective pressure is 100 pounds per square inch, as it is in aero engines, less than 2 per cent for higher, and more for lower mean pressures. The weight increase is almost negligible, being between one-tenth and two-tenths of a pound per horsepower.

Just as soon, however, as mufflers are demanded as a necessity the rotating cylinder engine must be changed or abandoned, as normally the exhaust valve is placed in the center of the head, usually held in place by an open cage screwed to the cylinder, discharging directly into the air. To attach a muffler will require a change of the cage to a closed form with pipe attachment and additional cooling to keep the now inclosed valve as cool as the open one. The muffler would have to be disposed symmetrically about the shaft and inwardly radial pipes held against centrifugal force at the muffler, fitted to the exhaust cage by slip joints. These pipes must, moreover, be circumferentially supported to prevent distortion by variable angular velocities, and they will impose additional windage resistance. The net effect will be a greater reduction of power and a greater increase in weight than muffler attachment imposes on fixed cylinder engines.

It goes without saying that no aero engine with tanks and connections complete is adapted to its purpose if tilting even to very considerable degrees interferes with its operation, and if it stops on tilting to any angle that is remotely possible in real flying it certainly must be rejected as failing in adaptability. There is considerable uncertainty as to the angle and direction of tilt that aero-engine adaptability requires, but the 15° required in the German and British contests seems to be a very modest requirement. No one will deny that the greater the angle of tilt and the more independent of direction, the better the adaptability factor. The conditions when tilting in flight may be quite different from those existing in a tilted engine at rest, especially when the motion is in curves developing centrifugal forces in all masses as well as in the lubricating oil and fuel feed system. Therefore, in considering engine independence of tilting, rapid change of motion as to speed and direction, but especially direction, must be included.

Any changes of direction of motion that the planes could withstand can have no appreciable effect on the motion or friction of the moving masses, but the effects on lubricating oil in the crank case or separate tank or pipes and on the gasoline in the carburetor float chamber, tank, and pipes may easily be as great as in extreme tilting. It is quite possible to imagine a resistance to flow, for example, purely gravitational or purely centrifugal, or both, great enough to cause engine trouble, in the one case from failure of the carburetor and in the other from overheating of bearings robbed of oil, or from flooding

of combustion chambers whose pistons get an excess. It is likewise possible that the water-circulation system be similarly deranged by opposition to circulation, causing steam to generate in a jacket, expelling all water, and causing an overheating, with a possibility of a crack, or by a drainage of water from the radiator vent. If an engine could so be designed that it could work on end, lying on its side, or even upside down for a short time, but preferably indefinitely, this would be the ideal. No such possibility is in sight, though engines are now operating in machines moving in curves and circles in horizontal planes, turning the engine on its side, but centrifugal force replaces gravity and no flows are disturbed. Similarly, looping or circle flying in a vertical plane turns the engine so that it operates first on end and then upside down, but, as before, the centrifugal force replaces gravity. Such is not the case, however, in a steep climb or descent nor in the uptilting of one end of the plane due to wind gusts. Here gravity flows are disturbed by the amount of side and end angle. Crank shafts and pin bearings must receive new and end thrusts which are not difficult to handle if they all are properly journaled.

Crank-shaft torque that is most uniform is best adapted to propeller drives, as these propellers being made of wood for lightness may be broken by sudden torque changes. Such changes also reduce the average propeller efficiency and produce reverse rocking forces in the machine frame. Any engine with insufficiently steady torque for propeller safety and for maintenance of high average efficiency may be adapted by addition of sufficient fly-wheel effect between engine and propeller. The same fly-wheel effect increases the crank-shaft torsional distortion and crank deflection and adds to engine weight. Engines that can give sufficiently uniform torque for the purpose without fly-wheels must displace others, and while the four cylinders in line engine seems to serve, it is true that the effort falls to zero on dead center. Anything less than four cylinders is out of the question, because the gas-pressure effort is entirely absent for a part or a whole stroke or more. Increase of number of cylinders over four makes the actual effort or resultant tangential force due to combined gas pressure and reciprocating inertia forces depart less and less from the constant mean effort and minimizes the angular velocity variations of the propeller without any other fly wheel than itself. From this standpoint the more cylinders the better, though from others discussed this is not the case.

Arrangement of a given number of cylinders radially about one crank produces the same torque curve as the same cylinders in line, provided their cranks in the latter case are separated by the same angles as their cylinder axes in the former. When, however, these cylinders in line have cranks parallel in pairs, as in the four and six crank arrangements, the torque will not be as uniform as when these are radially disposed about one crank. It appears, however, that the 6 cylinder in line, 6-crank arrangement, in which the torque never drops to zero, is quite uniform enough for practical work, and the 8 and 12 cylinder V arrangements are progressively better. There is no reason for adopting the radial arrangement if, as is the case, other objectionable elements are introduced, because the above is good enough and anything better not worth another disadvantage. Comparison of turning efforts for any arrangement of cylinders and

cranks is easy if they be plotted to a crank angle or crank path base by the usual standard methods. Many of these curves have already been worked out and may be found in the literature, including the inertia as well as gas-pressure force effects, and for such reference is made to the bibliography in the appendix. In no case may a fly wheel be introduced in aero engines to dampen torque variations because of weight limitations.

Balance of reciprocating parts in view of the light and flexible character of the engine supports which are part of the flying-machine structure, is probably the most important of the adaptability factors, because lack of balance means free shaking forces or moments on the whole system, and these being regular and periodic may periodically synchronize with the natural periods of wires, struts, and beams, and so cause displacements of such increasing amplitude as may be responsible for rupture. In no other engine, including the automobile, motor boat, and even the light shell of the racing boat, which comes nearest, is the support so frail and of such small mass capacity for absorbing vibration forces. Therefore, all unbalanced forces or couples and the full displacements or vibration of the engine as a unit are communicated directly to the flying-machine structure practically without any modification. Moreover, aero engine weight being so small in comparison with other engines, its own mass resists displacement by its free unbalanced forces and couples less than any other. For these reasons good balance is essential to aero engines, but absolutely perfect balance is not.

Shaking forces and moments in engines are due to both reciprocating and rotating masses, and vibration or rocking is the result of a failure to balance these forces and moments. Shaking forces due to rotating masses can be balanced perfectly by other rotating masses disposed on opposite sides of the shaft center with proper numerical relation between centers of gravity, radii, and weights. If the plane of rotation of the original rotating mass is not the same as that of its balance weight or weights, then there will be an unbalanced couple even if the centrifugal forces are in balance, unless balancing masses be disposed properly in separate planes, themselves properly related. Due observation of these simple and well-known relations make it a perfectly easy and simple matter to balance rotating parts of an engine by adding suitably disposed extra rotating balance masses. Such dead balance weights are, however, prohibited by the service requirements of least weight per horsepower, so the actual rotating working parts must themselves be so disposed as to balance each other. These parts include the cranks, crank pins, and rod ends principally, but also such small parts as the cams. If cranks, pins, and rod ends are balanced, other minor rotating parts may be neglected, though they set up inevitably some small shaking forces, especially as the speeds are so high, and these forces vary with the square of the speed.

Accordingly, to balance centrifugal forces and couples, due to cranks and their attached rotating masses, of fixed cylinder engines similar cranks must be suitably disposed with reference to the first. To avoid unbalanced couples with balanced forces more than two such cranks are necessary and in different planes. Two similar cranks at 180°, three at 120°, or any number equally spaced will result in force balance, because each introduces an equal force vector,

and, the sum of the vector angles being 360°, these vectors will form a closed equilateral force polygon, which means, of course, a zero resultant. Each set of such equally spaced cranks is characterized by a free couple, to balance which a similar and opposite couple must be introduced by adding a similar set of cranks with equal but reversed angular spacing.

Applying this reasoning to fixed cylinder engines, it appears that the least number of cranks that can give couple and force balance is four, set at 0°, 180°, 180°, and 0°, and the next smallest number, six, set at 0°, 120°, 240°, 240°, 120°, and 0°. Of course any multiples of these four and six crank arrangements will also yield such balance. This indicates a condition of inferiority of the fixed cylinders star engine with many cylinders circumferentially disposed about each crank, compared to the single-row and double-row V engines of equal number of cylinders. These star arrangements must have as many multicylinder stars, each working on its own crank, as the single and double rows of parallel arrangement has cylinders, in order to secure equally good rotating mass balance. This would impose on such fixed star cylinder engines an excessive number of cylinders, unless crank counterbalance weights were introduced, with consequent loss of the weight advantage otherwise due to the star arrangement.

Rotating cylinder star engines are peculiar, because with fixed cranks all parts of the engine are rotating—cylinders and frames in purely circular paths, pistons and wrist-pin ends of rods in a sort of oval path, while crank-pin ends of rods are fixed. According to this the cylinder and frame are in force balance when axis angles are equal, and all being in one plane there is no unbalanced moment. The centrifugal force due to the rotation of the piston is a maximum and radially outward when the piston is at outcenter, and a minimum at the incenter position with regular symmetrical gradations between. The net effect is a resultant force constant in amount and direction acting radially outward along the crank and exerting a lifting action if the crank points up, but not producing any vibration so long as the speed is constant. From the balance standpoint, therefore, the rotating star is superior to the fixed star arrangements, but is no better than the four and six cranks and their multiples with parallel rows of cylinders.

Reciprocating masses of fixed cylinder engines, such as pistons, wrist pins, and an appropriate part of the connecting rod, develop inertia forces for uniform rotary motion of the crank that can be expressed by an equation of the form of Fourier's infinite series, each successive term being proportional to a trigonometric function of a multiple of the angle of rotation from inner dead center and to increasing powers of the ratio of crank to connecting rod length. The reciprocating inertia force of one set of reciprocating parts is therefore the sum of an infinite number of forces of different periods or frequency, the first being largest and its period that of an engine speed, each successive one being smaller and of longer period. These reciprocating forces and the couples due to them must be balanced perfectly if possible; and if not, as well as possible. The forces due to valve and valve-gear reciprocation with accelerations determined by cam form may be neglected, though of course if these could be balanced in a simple way it would be desirable.

Balance of main reciprocating forces is possible only by opposing equal and opposite masses of equal simultaneous acceleration, or by arranging reciprocating masses in groups, so that the vector sums of their inertia forces become zero. There is, however, a partial balance possible by the use of crank counterweights or otherwise disposed rotating masses frequently used on stationary and locomotive engines, but normally prohibited on aero engines, on the principle of exclusion of all dead weights, even for balance purposes. A rotating crank counterweight exerts a radial centrifugal force which may be resolved into an axial and a right-angle component. This axial component may be made equal to the first-period inertia force, and, being, of course, opposite, it serves to balance this force. The right-angle component is, however, left and of equal intensity, and so, of course, are all higher period inertia forces. Such counterweights are therefore quite useless alone for flexibly supported engines, though when used with one particular combination of pistons and cylinders they become serviceable without very great weight increases. This special case is that of two cylinders set V at 90°, for here there are two first-period inertia forces at right angles, which are in balance with one counterweight, of mass equivalent to one of them for first-period forces, though higher period forces are still free.

As first-period inertia forces are similar to the axial components of rotating centrifugal forces, a similar grouping of multiples serves to produce balance effects. Such, for example, is the case with the four parallel cylinder four-crank arrangements in which, without balance masses, the first-period inertia forces are balanced, and, of course, also in the 8-cylinder V, which is a duplication of similar parts.

All combinations of arrangements of reciprocating parts for parallel, fixed star, and rotating star cylinders can be examined mathematically or graphically, and most of the proposed arrangements have been so studied and are reported in papers and books noted in the bibliography of the appendix. Of these perhaps the most elaborate is that of Kolsch in his book published in 1911, where conclusions are reproduced on mass balance of both rotating and reciprocating parts. Engines that are in complete mass balance without introduction of balance weights include the fixed cylinders 6, 8, 12, and 16 in a row each with its own crank, the 12 and 16 in two rows V with two cylinders per crank, the two cylinders opposed axes in line with two cranks and its multiple, and all rotating star cylinder arrangements having four or more cylinders per star. Those that are balanced for rotating masses and for the first period reciprocating mass forces but not higher ones, without balance weights, include the fixed cylinder engines of the four parallel cylinder four-crank arrangement and its twin or 8-cylinder V.

Introduction of balance masses gives complete balance to fixed cylinder star engines of four or more cylinders and a balance of first-period reciprocating inertia forces but not of higher ones to the 2 and 4 cylinder V and the 3-cylinder fixed star radial. This fundamental need of balance weights for fixed radial cylinders is also mathematically demonstrated by Milner, who says: "The engine will be completely balanced for primary and secondary forces by a mass $\frac{n}{2}$ times that one of the pistons ("n = number of cylinders") and diametrically opposite and same radius as the crank.

Of course this is in addition to the mass required to balance the rotating parts of the engine. The rotating cylinder engine ordinarily has one connecting rod heavier than the others which itself makes perfect balance impossible.

More cylinders and cranks than are necessary to give the required torque constancy, or the required balance, or the total power within the cylinder diameter limit can not be accepted. Each additional individual cylinder carries with it sources of additional trouble and increases the chances of unreliability, however much the consequences of failure may be reduced. The least allowable number on this basis appears to be 4 fixed cylinders in line or radial fixed or rotating. The maximum should be 6-cylinder 6-crank in line for balance or 8-cylinder V for torque, both advantages being equal in the 12-cylinder V, or twin 6. Of course the rotating cylinder engine of equal number of cylinders and symmetrical parts is just as good in torque and balance, and even a lesser number down to four equal in balance, though deficient in torque, but these rotating cylinders are in no way superior to the above arrangement. Stars fixed cylinders of equal number are equal in torque to the same number rotating if similarly disposed, but inferior in balance unless rotating counterweights are introduced, in which case equality results.

CONCLUSIONS AND RECOMMENDATIONS.

In the following brief statement of recommendations and conclusions, which are presented in the form of a list, no effort is made to develop arguments in support of each because it is believed that the text and appendices of the report themselves serve as sufficient support. No specific type of engine, form of part, material, or design constant is recommended, because it is believed that attention at this time must be directed mainly to methods of procedure that will lead to improvement. Naturally specific recommendations on design could be made, and these will be available at such time in the future as they may be desired.

1. The art has developed several typical arrangements of engine and several different designs of each type that may be regarded as of proven acceptability as to weight per horsepower of engine and thermal efficiency, but which require considerable work to perfect and standardize in detail and material without any further inventive work than properly constitutes part of the normal routine of research and designing engineers. These types are the 4 and 6 cylinders in line, each with its own crank, the 8 and 12 cylinder V with two cylinders per crank, all fixed cylinders and operating with both air and water cooling, preferably the latter, for long flights, and finally the radial star rotating air-cooled cylinder form for short flights.

2. There have also been developed a very large number of special designs of engine, which in some instances have been built and used but in others remain mere suggestions. Each one of these is practically an invention in itself, the precise practical value of which remains more or less in doubt. To properly develop the good points of these and other inventions to come, and to reject or eliminate unfavorable elements that are always present in new machines that have not yet stood the test of time, much work must still be done, quite independent of the research work so necessary for final perfec-

tion and standardization of the now acceptable and more or less largely used types noted above.

3. Direct governmental aid is an absolute necessity to the art, both for the perfection and standardization of accepted types and for encouragement of further invention. Private contributions should also be encouraged, whether for use in connection with the governmental establishment or independently.

4. There should be a regular buying program providing for the purchase of a fixed minimum number of aero engines yearly, to encourage existing engine builders to spend the money necessary to produce what is wanted to meet aviation specifications, because the best shops will not enter the field without some definite assurance of a fixed amount of business, for which they are, however, quite willing to compete.

5. The aviation engineers should standardize service specifications for engines, limiting the specifications strictly to those items that bear directly on service, so designers and builders may know definitely what conditions must be fulfilled without being hampered with purposeless limitations as to the means to be used by them.

6. The Government should conduct regular annual test competitions of engines on rules to be prepared and widely published at least 10 months in advance, and revised yearly immediately following the closing of the previous contest. For those engines that make the best records, substantial rewards must be provided in the form of cash prizes, or buying orders, or both. These cash prizes may be provided by Government appropriation, by private contribution, or both together.

7. There should be established a standardization research laboratory with a permanent staff of engineers selected for efficiency. This staff should conduct the competition tests, over not more than two months of the year, including the reports, and during the rest of the time should carry on tests for design and performance data of every engine of the accepted class noted in No. 1, but of no others. Other engines are to be admitted only on the recommendation of a second laboratory staff devoted to development of invention noted in No. 8.

8. There should be established a laboratory for development of inventions submitted by anyone, when those inventions seem promising. This staff must be quite independent of that of the standardization research laboratory noted in No. 7, and should preferably be located in quite a different place. Its engineers should be, in ability and temperament, quite different as well. When in this laboratory an engine, engine part, or accessory not in the accepted class, has been brought to a condition where its performance is equal or superior to what is in the accepted class, then it may be recommended to the standardization research laboratory for further study and perfection.

9. In at least one of the Government shops, possibly located in one of the navy yards, actual construction of engines of the accepted classes should be undertaken on about the same basis as is now followed for ships, the military shop competing with civilian shop in price and performance. Safeguards must be introduced to prevent any discouragement of private enterprises or charges of unfairness in this competition.

10. Officers and enlisted men who may be charged with the care of aero engines in service should be assigned to duty, first, in the Government aero engine shops, then in both the standardization

research and the invention development laboratories, and finally in the engineering office noted in No. 11, for instruction.

11. There should be established a staff of supervising and designing engineers for internal combustion engines. This staff should prepare all purchasing specifications, prepare engine test competition rules, receive and use all standardization data from the laboratory, exercise general direction over both the laboratories, and prepare detailed drawings for the shops.

12. There should be established the closest possible relation between aero-engine development and that for other classes of internal combustion engines in which the military now has or may in the future have an interest. Among these are included submarine engines, ship and launch engines, automobiles and auto trucks, gun and transport traction engines, and stationary electric generation sets for wireless, mine firing, searchlights or general service. The same designing staff, laboratories, and shops that should be established for aero engines can also advantageously undertake similar work for these other internal combustion engines, as most of the fundamental training, knowledge, data, methods, and skill required for the one is also of equal service to the others. Similarly, officers and enlisted men of those other branches of the service can be given adequate instruction by temporary assignments to the shop, laboratories, and engineering office.

13. Publicity of data should be promoted by governmental publication of reports to keep alive the general interest in the needs of the Military Establishment in the internal combustion engine field, because the greater the interest the greater the contributions of the profession. This publication may also take the form of papers prepared by engineers of any of the various staffs and presented to the national engineering societies. Not only should domestic results be thus given publicity, but all foreign papers and official reports of value should be translated and republished. Whenever data is regarded as being strictly military in value and where publication is therefore deemed inadvisable, such material can, of course, be withheld, but it is believed that in general both Army and Navy have more to gain than to lose by publicity of engineering data on engines.

14. It is regarded as of the utmost importance that advantage be taken by the Government of the service of such civilian engineers as have given special attention to the study, commercial development, and use of internal combustion engines of all classes, and more particularly those not engaged in manufacturing, though not excluding those of high professional standing that may be so engaged. The special knowledge, skill, and experience that these men can bring immediately to the service of the Military Establishment should prove as invaluable here as it has abroad, in Germany, for example, first in organizing the various working staffs recommended above, and later in working with them. Advantages may also be taken of the laboratories of such of the engineering schools as have specialists of the above type on their faculties, or as may be located in large centers where such men not associated with engineering schools may have their regular offices.

15. No recommendation is made on the details of the organization of these various staffs and their coordination with the existing Army and Navy Departments and bureaus except as to necessity.

NOTE.—Part 3 omitted. See note on Preface, page 187.

O

AERONAUTICS

SECOND ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TOGETHER WITH THE

MESSAGE OF THE PRESIDENT OF THE UNITED STATES

TRANSMITTING THE REPORT

FOR THE FISCAL YEAR ENDED JUNE 30

1916

THIRD EDITION

DECEMBER 6, 1916.—Read; referred to the Committee on Naval Affairs and ordered to be printed, with illustrations

WASHINGTON
GOVERNMENT PRINTING OFFICE
1917

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REPORTS.[1]

[1] Reports 1 to 7, inclusive, published in first annual report.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

MUNSEY BUILDING, WASHINGTON, D. C.

Prof. William F. Durand, *Chairman*,
Leland Stanford Junior University, Stanford University, Cal.
Naval Constructor Holden C. Richardson, United States Navy, *Secretary*,
Munsey Building, Washington, D. C.
Prof. Joseph S. Ames,
Johns Hopkins University, Baltimore, Md.
Capt. Mark L. Bristol, United States Navy,
Commanding Officer, U. S. S. *North Carolina*.
Prof. John F. Hayford,
Northwestern University, Evanston, Ill.
Prof. Charles F. Marvin,
Chief United States Weather Bureau.
Hon. Byron R. Newton,
Assistant Secretary of the Treasury, Treasury Department.
Prof. Michael I. Pupin,
Columbia University, New York, N. Y.
Brig. Gen. George P. Scriven, United States Army,
Chief Signal Officer, War Department.
Lieut. Col. George O. Squier, United States Army,
In charge Aviation Section, War Department.
Dr. S. W. Stratton,
Director Bureau of Standards.
Dr. Charles D. Walcott,
Secretary Smithsonian Institution.

EXECUTIVE COMMITTEE.

Dr. Charles D. Walcott, *Chairman*.
Naval Constructor H. C. Richardson, United States Navy, *Secretary*.

Prof. Joseph S. Ames.
Capt. Mark L. Bristol, United States Navy.
Prof. Charles F. Marvin.
Prof. Michael I. Pupin.
Lieut. Col. George O. Squier, United States Army.
Dr. S. W. Stratton.

MESSAGE OF THE PRESIDENT.

To the Senate and House of Representatives:

In compliance with the provisions of the act of Congress approved March 3, 1915 (naval appropriation act, Public No. 273, 63d Cong.), I transmit herewith the Second Annual Report of the National Advisory Committee for Aeronautics, for the fiscal year ended June 30, 1916.

WOODROW WILSON.

THE WHITE HOUSE, *December 6, 1916.*

[Extract from Public Act No. 271.]

In the naval appropriation act (Public, No. 271, 63d Cong.) approved March 3, 1915, the following provision was made for a national advisory committee for aeronautics:

An advisory committee for aeronautics is hereby established, and the President is authorized to appoint not to exceed twelve members, to consist of two members from the War Department, from the office in charge of military aeronautics; two members from the Navy Department, from the office in charge of naval aeronautics; a representative each of the Smithsonian Institution, of the United States Weather Bureau, and of the United States Bureau of Standards; together with not more than five additional persons who shall be acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences: *Provided*, That the members of the advisory committee for aeronautics, as such, shall serve without compensation: *Provided further*, That it shall be the duty of the advisory committee for aeronautics to supervise and direct the scientific study of the problems of flight, with a view to their practical solution, and to determine the problems which should be experimentally attacked, and to discuss their solution and their application to practical questions. In the event of a laboratory or laboratories, either in whole or in part, being placed under the direction of the committee, the committee may direct and conduct research and experiment in aeronautics in such laboratory or laboratories: *And provided further*, That rules and regulations for the conduct of the work of the committee shall be formulated by the committee and approved by the President.

That the sum of $5,000 a year, or so much thereof as may be necessary, for five years is hereby appropriated, out of any money in the Treasury not otherwise appropriated, to be immediately available, for experimental work and investigations undertaken by the committee, clerical expenses and supplies, and necessary expenses of members of the committee in going to, returning from, and while attending, meetings of the committee: *Provided*, That an annual report to the Congress shall be submitted through the President, including an itemized statement of expenditures.

LETTER OF SUBMITTAL.

National Advisory Committee for Aeronautics,
Munsey Building,
Washington, D. C., December 4, 1916.

The President:

In compliance with the provisions of the act of Congress approved March 3, 1915 (naval appropriation act, Public, No. 273, 63d Cong.), the National Advisory Committee for Aeronautics has the honor to submit herewith its second annual report, including estimates and recommendations, and a statement of expenditures to June 30, 1916.

In order to carry out its purposes and objects as defined in the act of March 3, 1915, the committee submits herewith certain recommendations and an estimate of expenses for the fiscal year ending June 30, 1918. The estimates in detail were submitted through the Secretary of the Navy.

Attention is invited to the appendixes of the committee's report, and it is requested that they be published with the report of the committee as a public document.

It is apparent to the committee that there is a large amount of important work to be done to place aeronautics on a satisfactory foundation in this country.

Very respectfully,

Charles D. Walcott,
Chairman Executive Committee.

SECOND ANNUAL REPORT OF THE NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
MUNSEY BUILDING,
Washington, D. C., December 4, 1916.

To the Congress:

In accordance with the provisions of the act of Congress, approved March 3, 1915, establishing the National Advisory Committee for Aeronautics, the committee here submits its second annual report.

The general report reviews the work of the committee during the past year, and contains estimates for the fiscal year 1918 and certain recommendations for the consideration of Congress. Technical reports covering various subjects under investigation during the past year are submitted as appendices.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

The National Advisory Committee for Aeronautics was established by Congress by act approved March 3, 1915. Under the law, the committee is charged with the supervision and direction of the scientific study of the problems of flight with a view to their practical solution, and the determination of the problems which should be experimentally attacked, their solution, and their application to practical questions of aeronautics. In the event of a laboratory or laboratories, either in whole or in part, being placed under the direction of the committee, the committee may direct and conduct research and experiments in aeronautics in such laboratory or laboratories.

The committee has 12 members, appointed by the President. As authorized by Congress, the personnel of the committee consists of 2 members from the War Department, from the office in charge of military aeronautics; 2 members from the Navy Department, from the office in charge of naval aeronautics; a representative each of the Smithsonian Institution, of the United States Weather Bureau, and of the United States Bureau of Standards; and not more than 5 additional persons acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences.

During the past year there was one change in the membership of the committee, caused by the retirement of Lieut. Col. Samuel Reber, United States Army, who was succeeded on the committee by Lieut. Col. George O. Squier, United States Army, as officer in charge of the Aviation Section of the Army.

The organization of the Advisory Committee, as of October 5, 1916, is as follows:

Prof. William F. Durand, chairman.

Naval Constructor H. C. Richardson, United States Navy, secretary.

Prof. Joseph S. Ames.

Capt. Mark L. Bristol, United States Navy.

Prof. John F. Hayford.

Prof. Charles F. Marvin.

Hon. Byron R. Newton.

Prof. Michael I. Pupin.

Brig. Gen. George P. Scriven, United States Army.

Lieut. Col. George O. Squier, United States Army.

Dr. S. W. Stratton.

Dr. Charles D. Walcott.

RELATION OF WORK OF THE ADVISORY COMMITTEE TO ARMY AND NAVY.

In the course of the past year a number of problems of importance to the Army and Navy have come to the attention of the committee, and steps have been taken toward aiding these departments in arriving at solutions of the problems presented. Report No. 11 on gasoline carburetor design, which has just been prepared, and an investigation of air propellers, which is about to be inaugurated by the committee, will both be of value to the military branches of the Government. In the exercise of its function for securing cooperation the committee has enlisted the interest of the Bureau of Standards in the determination of the characteristics of the materials entering into airplane construction and in particular into the construction of air propellers, and the Bureau of Standards is already engaged on these problems. Through its subcommittee on motive power, the Advisory Committee has effected an active cooperation between the Government departments concerned and the Society of Automobile Engineers, which it is expected will at an early date enable the committee to place valuable information at the disposal of the Government departments and the aeronautic industry in general.

AERIAL POSTAL SERVICE.

At the annual meeting on October 5, 1916, a representative of the Post Office Department was present, at the request of the committee, and informed the committee of the unsuccessful efforts of the Post Office Department to inaugurate an aerial postal service in Alaska and from New Bedford to the island of Nantucket.

It was apparent that, although aviation has made great strides in the past two years, the conditions of both of these routes were so severe as to deter responsible bidders from undertaking this service. After discussion of the entire matter, the committee concluded that the time has arrived when it is perfectly practicable to inaugurate such air service, and recommends to Congress that the Post Office Department be authorized to establish one or more experimental routes, with a view to determining the accuracy, frequency, and

rapidity of transportation which may reasonably be expected under normal and favorable conditions, and therefrom to determine the desirability of extending this service wherever the conditions are such as to warrant its employment.

The Advisory Committee will, if called upon, assist and advise the Post Office Department in the undertaking above recommended.

WORK OF THE COMMITTEE.

During the past year the Advisory Committee has held two meetings—on October 15, 1915, and April 20, 1916. The business transacted at these meetings appears under the various subjects treated in this report. At the meeting on October 15, 1915, the regulations were amended to provide that the secretary of the Advisory Committee, who had been ex officio secretary of the secretary of the executive committee, be made a full voting member of the executive committee. This amendment was approved by the President on October 25, 1915. At the meeting on April 20, 1916, the committee adopted an amendment to the regulations changing the date of the annual meeting to the Thursday after the first Monday in October in order to enable it to give consideration to the preparation of estimates of expenses for the following fiscal year, which are required by law to be submitted by October 15 of each year. This change was approved by the President under date of April 27, 1916.

THE EXECUTIVE COMMITTEE.

For carrying out the work of the Advisory Committee the regulations provide for the election annually of an executive committee to consist of seven members and the secretary, ex officio. The organization of the executive committee, as of October 5, 1916, is as follows:

Dr. Charles D. Walcott, chairman, Secretary Smithsonian Institution.

Naval Constructor H. C. Richardson, United States Navy, secretary.

Prof. Joseph S. Ames, physicist, Johns Hopkins University.

Capt. M. L. Bristol, United States Navy.

Prof. Charles F. Marvin, Director United States Weather Bureau.

Prof. Michael I. Pupin, physicist and electrical engineer, Columbia University.

Lieut. Col. George O. Squier, United States Army.

Dr. S. W. Stratton, Director Bureau of Standards.

The program of work approved by the Advisory Committee was entrusted to the executive committee for execution. The executive committee was directed to consider a program of investigation and procedure intended to carry into effect the purposes of the act creating the Advisory Committee and to report the same with recommendations. The executive committee accordingly held regular monthly meetings throughout the year, and in addition held three special meetings. The reports of work done by the executive committee and its recommendations have been approved by the general committee and are incorporated into this report.

To facilitate the work of the committee the following subcommittees were formed and progress has been made on the general lines indicated in the designations of these committees:

Relation of the atmosphere to aeronautics.
Standardization and investigation of materials.
Aeronautical nomenclature.
Radiator design.
Motive power.
Specifications for aeronautic instruments.
Design, construction, and navigation of aircraft.
Site for experimental field.
Governmental relations.
Bibliography of aeronautics.

TECHNICAL REPORTS.

During the past year, owing to the very limited funds available for the use of the committee, only one contract for a special report was placed. This was for an investigation and report on the subject of gasoline carburetor design. Technical Reports Nos. 8 to 12, inclusive, are submitted herewith as appendixes.

Report No. 8 prepared by the subcommittee on specifications for aeronautic instruments, covers the subject of general specifications for aeronautic instruments. The object of this report is to acquaint manufacturers with the types of instruments required for aeronautic purposes and the conditions to be met in the uses of these instruments in connection with the navigation and operation of aircraft.

Report No. 9, covering the subject of aeronautical nomenclature, was prepared by the subcommittee on aeronautical nomenclature. The subcommittee charged with its preparation very thoroughly investigated the new terms which have come into use with the development of aviation and after consideration of such limited contributions as were available on this subject, and the comments of aviators of the Army and Navy, and of manufacturers, adopted this nomenclature for the purpose of eliminating the confusion that has already come into existence in the use of aeronautical terms. In the preparation of this nomenclature, it appeared unnecessary to define any terms already well established in other branches. Particularly, it appeared unnecessary to define such terms as are familiar to all users of automatic engines; so that the nomenclature adopted by the committee principally comprises terms that are peculiar to, or new in, aeronautics.

Report No. 10 is a preliminary report of progress in the design and construction of a suitable form of muffler for aeronautic engines. This is a rather difficult problem and requires a large amount of experimental work. In this preliminary report it is pointed out that there are other than exhaust noises to be contended with even more difficult of elimination. This special report was prepared and submitted by Profs. H. Diederichs and G. B. Upton, of Cornell University, Ithaca, N. Y., under contract made in June, 1915. As definite results have not as yet been attained, experimental work and investigation will be further pursued during the present fiscal year.

Report No. 11, previously referred to, is a very complete and valuable report on gasoline carburetor design and throws light on a rather neglected subject. This special report was prepared and submitted by Prof. Charles E. Lucke, of Columbia University, New York, N. Y.

Report No. 12, entitled "Experimental researches on the resistance of air," by L. Marchis, professor in the Faculty of Sciences of Paris, is an admirable résumé of the status of experimental research at the present time. It is not an original paper, having been translated from the French by Prof. William F. Durand, a member of the committee.

A report on the "Physics of the air" has been prepared by the subcommittee on the relation of the atmosphere to aeronautics and printed in pamphlet form by the Smithsonian Institution. This report should be valuable to aviation officers, who obviously desire to know the causes of atmospheric phenomena, as well as to practical aviators, as many of the results, especially those given in tables and diagrams, are in form for quick and easy use by the practical pilot. The report as published is an abstract from the complete report of that material which is of special interest to navigators of the air.

GENERAL PROBLEMS.

The problems enumerated in the first annual report of the committee constituted the program of work during the past year. These problems are considered of immediate importance, and will be attacked on a larger scale by the committee as soon as funds are made available for the purpose.

A. Stability as determined by mathematical investigations.—The work inaugurated by Asst. Naval Constructor J. C. Hunsaker, United States Navy, on these lines has been extended, and is now being carried on by Prof. A. Klemin, who has succeeded Naval Constructor Hunsaker at the Massachusetts Institute of Technology. Prof. Klemin is endeavoring to reduce this problem to a practical form, which will permit of the determination of the proper proportions of the different elements of the airplane design in order to insure the desired qualities, and it is expected the committee will be able to obtain a report on this work during the coming year.

B. Air speed meters.—A number of engineers are engaged in solving this problem, and a preliminary design has been worked out at the Washington Navy Yard, and has shown fair results in actual service. Upon the completion of experiments the data relative to same will be available to the committee.

C. Wing sections.—No direct investigation bearing on the improvement of the form of the wing itself has been made, but work of considerable interest has been carried out at the Massachusetts Institute of Technology under the direction of Naval Constructor Hunsaker, and reports have been published in a number of aeronautical papers and in Smithsonian Miscellaneous Collection, volume 62, No. 5, June 30, 1916. These reports include discussions of the advantages to be gained by changing the relations and proportions of the upper and lower wings in a biplane arrangement and also the effects produced in the triplane arrangement. Investigations show

that by giving the upper wing a strong stagger and a larger angle of attack than the lower wing it is possible to obtain practically any desired degree of stiffness longitudinally, and this can be done even without the use of stabilizing tail planes. This contribution places this feature of design in a very satisfactory condition, analogous to that of the design of ships, in which the metacentric height is made to suit the conditions of service. It appears that for general service, and particularly for military service, an airplane having a very moderate longitudinal stiffness and ample controls for modifying the attitude of the machine, combined with proper damping surfaces, affords the most satisfactory solution.

D. Engines.—In addition to the investigation of mufflers reported last year, the committee has inaugurated an investigation of the subject of gasoline carburetors, but otherwise, due to the limited funds, no direct investigations have been carried on by the committee. However, the results of the meeting of June 8, 1916, when the committee held an open conference with representatives of several manufacturers of aeronautic engines, have rapidly accumulated, and through cooperation with the Society of Automobile Engineers, through the subcommittee on motive power, the committee is closely in touch with engine development and is cooperating in every manner possible, principally by bringing the War and Navy Departments in close touch with this society, and thereby the manufacturers, so that many of the problems of engine design are already well in hand.

E. Propellers.—Very recently the propeller problem has assumed considerable importance, due to the difficulties experienced with wooden propellers handling large power at high speeds of revolution. This problem has been particularly serious in the air service of the War Department on the Mexican border because of the severe climatic conditions, which have seriously affected the life of the propellers. These problems are principally problems of mechanical construction and not problems of design involving the form of the propellers or their efficiency, and on the latter subject no progress has been made, so far as is known to the committee, and no satisfactory engineering data is available for design purposes.

The committee has just entered into a contract with Prof. William F. Durand, which will be carried out at Leland Stanford Junior University, for an investigation of models of propellers with a view to establishing engineering data for design.

F. Form of airplane.—This has already been referred to under "A."

G. Radio telegraphy.—No particular progress is reported on this line, although both the War and Navy Departments have carried on investigations on these lines, and considerable success has been attained in recent experiments in the Army.

The Navy has also experimented at Guantanamo and carried on work at Pensacola. The Bureau of Steam Engineering of the Navy Department has also provided a number of airplane radio sets, and the Bureau of Standards has developed a radio direction indicator which will be given practical trials in the naval service at an early date.

PHYSICAL PROBLEMS.

Besides the more general problems, the following problems of a physical rather than aeronautical nature are of particular interest. These problems were noted in the first annual report, but, owing to the lack of funds, very little progress has been made toward their solution during the past year.

A. Noncorrosive materials.—Investigation of noncorrosive materials at the Bureau of Standards has been continued, but no report is yet available.

B. Flat and cambered surfaces.—No progress is reported.

C. Terminal connections.—No additional progress is reported.

D. Characteristics of constructive materials.—This work has been begun by the Bureau of Standards, but no report is yet available.

E. Generation of hydrogen.—The Bureau of Steam Engineering of the Navy Department has taken up this work in connection with the installation of hydrogen plants aboard ships, but no report is available.

F. Standardization of nomenclature.—This subject is covered by Report No. 9, which accompanies this report.

G. Standardization of specifications for materials.—This subject is an extremely broad one and is being handled by the committee in cooperation with the Society of Automobile Engineers. One promiment manufacturer of aircraft has already developed a very good set of specifications for his own use, but these specifications are more or less particular in form, because of the present unusual condition of the material market.

H. Bibliography of aeronautics.—Negotiations are under way for the issuance of a report bringing this subject up to date.

I. Collection, revision, and issuance of reports covering the state of the art of aeronautics have not been undertaken as it now appears probable that it will be unnecessary because of the number of good publications which already exist.

J. Limitation of size.—No steps have been taken by the committee toward the solution of this problem. An interesting article on this subject by F. W. Lanchester, member of the British Advisory Committee for Aeronautics, is noted in the Scientific American of June 3, 1916.

K. Causes of accidents.—Although this problem is a serious one, the committee has not been able to inaugurate the work proposed.

CO-OPERATION WITH AERONAUTIC INDUSTRY.

At the meeting of the executive committee on May 11, 1916, an important step was taken when it was decided to invite representatives of different aeronautic engine manufacturers to be present at a meeting of the executive committee, to discuss the engine problem the committee with a view to bringing out clearly the difficulties encountered by manufacturers in meeting the exacting demands of aviators and with a view to a more complete understanding between the builders and users of aeronautic engines. Accordingly, the executive committee held a public session on June 8, 1916, at which were present representatives of various manufacturers of aeronautic engines and

in addition to the members of the committee representing various Government branches, there were also present, on invitation of the committee, special representatives of the War and Navy Departments familiar with the practical problems involved in the use and development of aeronautic engines. The Naval Consulting Board of the United States was also represented.

The proceedings of this meeting, being of great interest to the aeronautic industry in general, have been given wide circulation by the committee. One of the results of the meeting has been the inauguration of an important movement for the development of satisfactory aeronautic engines. This will undoubtedly serve to stimulate cooperation between the Government departments—the principal users of aircraft at present—and the principal producers of aeronautic engines. Thus, the Advisory Committee has already inaugurated one of the most important services for which it was established. Through the agency of the thoroughly established organization of the Society of Automobile Engineers, many of the steps which impeded progress in the development of the automobile should be avoided in the further development of the aeronautic engine, and powerful and competent agencies brought to bear to aid in the solution of difficult problems.

From such information as the committee is able to obtain, it now appears that the aeronautic engine problem, which was in an unsatisfactory condition a year ago, has greatly improved.

STANDARDS OF WORK.

The Government agencies fully appreciate the necessity of the adoption of standards of work and are taking steps toward the securing of such standards. It is of the greatest importance that the manufacturers of aircraft should work in harmony with the Government, at present the principal consumer, and that they should come to definite agreements as to the standards of work necessary to facilitate production and repairs. The committee, through the subcommittee on motive power, is assisting in this work of cooperation.

EXISTING FACILITIES FOR AERONAUTIC INVESTIGATIONS IN GOVERNMENT DEPARTMENTS.

Limited facilities for aeronautic investigations in Government departments were reported in the first annual report, and it is anticipated that extensive additions to the existing facilities will be developed during the year 1917.

QUARTERS FOR THE COMMITTEE.

In the appropriation for the expenses of the committee for the fiscal year 1917, provision was made for the rental of quarters. The committee reports that quarters in the Munsey Building, adequately meeting the needs of the committee at present, have been secured. However, the increase in work contemplated by the committee, and authorized in the last appropriation, will require additional office space, and the committee recommends that the amount for office rent be increased as indicated in the estimates of expenses for the next fiscal year.

FINANCIAL REPORT.

Out of the appropriation of $5,000 for the expenses of the committee for the fiscal year 1916, the committee reports expenditures and obligations during the year amounting to $4,904.28, itemized as follows:

Expenditures and obligations incurred under appropriation "Advisory Committee for Aeronautics, 1916."

Traveling expenses	$862.70
Furniture and equipment	363.57
Printing	419.60
Stationery	52.42
Telegrams	5.99
Clerical services	1,200.00
Special report (Carburetor investigation by Prof. Charles E. Lucke, of Columbia University, New York, N. Y.)	2,000.00
Total	4,904.28
Balance turned into Treasury	95.72
Amount of appropriation	5,000.00

ESTIMATES AND RECOMMENDATIONS.

The following estimates of expenses for the fiscal year 1917-18 have been submitted by the committee in due form:

For scientific research, technical investigations, and special reports in the field of aeronautics, including the necessary laboratory and technical assistants; traveling expenses of members and employees; rent (office in the District of Columbia not to exceed $1,500); office supplies, printing, and other miscellaneous expenses; clerks; draftsmen; personal services in the field and in the District of Columbia: *Provided*, That the sum to be paid out of this appropriation for clerical, drafting, watchmen, and messenger service for the fiscal year ending June thirtieth, nineteen hundred and eighteen, shall not exceed $12,000; in all, $107,000.

It is strongly recommended by the committee that the next appropriation for the direction and conduct of research and experiment in aeronautics, and the committee's work in general, be made in lump sum with limitations only on clerical and drafting services and office rent in the District of Columbia.

For the fiscal year 1916-17 there was appropriated $85,000, as follows, which became available August 29, 1916:

Traveling expenses of members and employees		$2,000
2 technical assistants, at $2,500 each	$5,000	
1 clerk	1,500	
1 clerk	1,000	
1 draftsman	2,000	
1 draftsman	1,000	
2 laborers, at $660 each	1,320	
3 mechanics, at $1,200	3,600	
		15,420
Rental of office		1,200
Supplies		7,800
Special reports		5,000
Movable combination field office, machine shop, dynamometer shed, hangar, and power plant		15,000
Dynamometer carriage and truck		18,000
Airplane, including motor		10,000
Transmission dynamometer		1,000

Ripograph	$1,000
Stabilizer	1,500
Anemometers, barographs, inclimometers, incidence indicators	1,500
Miscellaneous supplies, spare parts for operation of field plant	5,580
Total	85,000

Owing to the many changes that have occurred in the rapid advance in the development of the art of aeronautics, it will be necessary to obtain further authority before a considerable portion of this appropriation can be used to the best advantage. The committee therefore also recommends that authority be granted to expend any remaining balances of the appropriation for the fiscal year 1916–17 under the same terms recommended for next year's appropriation. This would leave the committee free to use its funds in the most effective manner and transmit to Congress an itemized account of expenditures in its annual report.

CONCLUSIONS.

The carrying on of the work authorized in the last appropriation depends largely on the availability of a suitable field for the location of the field laboratory and its equipment. In the last appropriation for the War Department Congress authorized the securing of fields for Army purposes, and the War Department has called on this committee for its advice respecting the conditions governing the selection of a suitable site for a proving ground for aircraft.

It seems to the committee that considerable advantage would be gained if the site selected for the War Department would also be such as to be suited to the requirements of this committee, as well as to the Navy Department, and, with this purpose in view, the committee has solicited the advice of both the Navy and War Departments in this matter. As a result the committee has been able to advise each as to the requirements of the other and of this committee in the location of such a proving ground, and the site finally selected by the War Department met with the approval of that department and of this committee. Neither this committee nor the Navy Department has authority or funds available for purchasing a site, the War Department only having authority and funds.

It is contemplated that a part of any site selected by the War Department may be made available for certain uses of the Navy Department and of this committee, or, if this is not approved, additional territory adjoining the War Department site can be obtained for these purposes.

The committee strongly recommends that the activities of the War and Navy Departments and of this committee on these lines should be carried out in as close proximity as is possible, to their mutual interest and the advantage of the Government.

The site contemplated by the Army is on a branch of the Chesapeake Bay, sufficiently remote from the entrance of the bay to insure reasonable immunity from interference due to the operations of a possible enemy. The location is such as to be readily accessible to Government officials located in Washington who have the direction of the important developments contemplated. It is also reasonably accessible to the principal manufacturing centers of the East, and

therefore to the principal manufacturers who are interested in the production of the devices necessary to the War and Navy Departments.

The climatic conditions are temperate and well suited to the purposes intended, permitting of work all the year around. The location is also such as to afford unusual facility for the development of aircraft and their accessories suited to work on land and water under nearly all conditions which must be met in service. This feature alone makes it very desirable from the point of view of both the War and Navy Departments, as the development of aircraft suited to operation from rough water is one of the most important problems requiring solution in both services.

The committee feels that if the activities of the War and Navy Departments and of this committee can thus be concentrated at or near one station the greatest good will result, and therefore recommends that in the legislation for the War and Navy Departments and for this committee everything that would tend toward the accomplishing of this concentrated effort be given the most careful consideration.

Respectfully submitted.

WILLIAM F. DURAND, *Chairman.*

TECHNICAL REPORTS

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

REPORTS Nos. 8 TO 12.

REPORT No. 8.

GENERAL SPECIFICATIONS COVERING REQUIREMENTS OF AERONAUTIC INSTRUMENTS.

By The NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS.

REPORT No. 8.

GENERAL SPECIFICATIONS COVERING REQUIREMENTS OF AERONAUTIC INSTRUMENTS.

By The National Advisory Committee for Aeronautics.

INTRODUCTION.

For the information of those concerned with the use or production of instruments used in the navigation and operation of aircraft, the following general list and specifications have been prepared with a view to indicating the lines on which development is required, and the restrictions and difficulties to be overcome in the design and construction of aeronautical instruments:

Barometer or altimeter.
Compass.
Air speed meter.
Inclinometer.
Drift meter.
Tachometer.
Oil gauge.
Oil pressure gauge.
Gasoline gauge.
Gasoline flow indicator.
Distance indicator.
Barograph.
Angle of attack indicator.
Radiator temperature indicator.
Gasoline feed system pressure indicator.
Sextant.
Airplane director.

GENERAL REQUIREMENTS.

All indicating instruments required in the navigation of aircraft should be as compact, rugged, and light as is consistent with accuracy, reliability and durability, and with ease of reading. Such instruments must be free from the influence of the following disturbing effects, excepting, of course, those effects on which they depend for their operation, viz, vibration, change of altitude and change of temperature.

BAROMETER OR ALTIMETER.

Barometers or altimeters must be sensitive and of open scale, and the lag in their operation should be the absolute minimum obtainable. When operating in a fog it is essential that the distance above the surface should be known within very close limits. Such instruments, of course, are dependent on barometric pressure and on varia-

tions of barometric pressure from the time of the start of a flight until the completion of a flight, which can not be provided for, but aside from this error their indications should be substantially accurate once they are adjusted at the point of departure. It is, therefore, necessary that the scale should be of equal divisions, as otherwise a change of zero to meet change of barometric height will introduce an error. Their location on the airplane must be carefully chosen so that their indications will not be influenced by the velocity pressures in flight.

COMPASS.

Compasses should have as high a directive force as is consistent with restricted dimensions. Provision should also be made in the compass mounting for compensating for the presence of magnetic material in the construction of the airplane, particularly compensation for heeling and dipping errors. In order that the directive force shall not be abnormally reduced by such compensation, it is, of course, desirable that the structure should avoid the use of magnetic materials in moving parts near the compass location, such as the control columns, shafts, and leads.

AIR SPEED METER.

An air speed meter should indicate reliably the speed through the air, and should be free from the effects of accelerations, as when the machine is banking strongly in a turn the effect of gravitation is augmented by the presence of the centrifugal force. As the sustaining power of an airplane is dependent upon the density of the atmosphere, it is considered that air speed meters which are dependent on the pressure due to velocity will be a safer form of indicator than a true anemometer type.

It is essential that the indicators shall be particularly sensitive and have an open scale reading at velocities approaching a stalling speed, which is the lower limit of safe flying speed. It is also necessary that they should indicate high speeds accurately, in order that excessive speed may be avoided when gliding. Excessive speed in gliding involves danger when a machine is brought up too sharply, as the combination of high speed and the maximum lift factor may readily stress the machine beyond safe limits. Also, when flying at high speed the angles of attack are small, and there is danger of the airplane entering a critical condition in which the flow of air may develop radical changes of state, and consequently great changes in the lifting power available. Air speed meters should be capable of calibration immediately prior to a flight. Air speed meters of the Pitot type dependent on a fluid are subject to gravitational errors when banking. They are also subject to error due to heeling or diving. Unless the leads from the Pitot tube to the indicating instruments are sufficiently large, there is also danger of a serious lag in indications.

INCLINOMETER.

Inclinometers of the pendulum or spirit-level type are inaccurate in the presence of accelerations and are only useful as a general check as to the attitude of the machine when flying in a fog. It is very desirable that an indicator free from these defects should be devel-

oped. A gyroscopic base line is considered desirable not only for purposes of indicating inclination but as affording a base line for sighting and for the use of instruments of navigation.

DRIFT METER.

Drift meters are of two types—one designed for the purpose of indicating leeway over the surface for use in connection with navigation, and the other more properly termed "side slip indicator" for the purpose of indicating whether or not the machine is flying square to the wind. The latter designation is considered preferable for indicating the attitude of the machine. For navigating over the ground the course is readily determined by ascertaining the apparent motion of objects on the surface, and the same method is available for navigating over the water, provided there is a definite object on which to sight. One type of drift meter indicates by the streaking of waves across the objective glass of the instrument as apparent drift, but as the particles of the waves themselves which indicate this streaking have a velocity of their own, such indications are subject to error. If the surface wind direction or velocity were known, correction might be made, but when flying at an altitude of several thousand feet it is very likely that the airplane itself may be in an entirely different current of air than that present at the surface. In addition to this, tidal currents may also affect the velocity of the water particles. Two forms of side slip indicators exist, the simplest form being that of the well-known string or pennant, but the latter can not be used satisfactorily in the wake of a tractor propeller. The other type consists of a very sensitive pendulum which indicates whether or not lateral accelerations are present, as will be the case for a machine which is not properly balanced laterally, but such an instrument is subject to the defect that if the machine is side slipping laterally at a constant speed, lateral acceleration is no longer present. It can only be depended on to indicate initial disturbances.

TACHOMETER.

Tachometers should be absolute in their indications, and if electrical should not be subject to disturbances in the conductivity of circuits from any cause, or to deterioration of magnetism of a permanent magnet.

OIL GAUGE.

Oil gauges must definitely indicate the amount of oil present in the crank case.

OIL-PRESSURE GAUGE.

Oil-pressure gauges must accurately indicate the pressure in the oil system and should also indicate that the flow of oil is undisturbed.

GASOLINE GAUGE.

Gasoline gauges should indicate the amount of gasoline available in the main tanks, and should not depend on the visibility of gasoline in a glass tube, as, due to the transparency of gasoline, a full tank and an empty tank would give the same indications. Mechanical indicators are considered preferable.

GASOLINE-FLOW INDICATOR.

Gasoline-flow indicators should depend on mechanical means of indicating that the gasoline is being supplied from the main tanks to the service tanks.

DISTANCE INDICATOR.

For navigation at sea or over unknown country, it is desirable that a record of distance flown through the air should be available. If it were not for the fact that the slip of the propeller depends largely on the load of the machine, and whether or not the machine is climbing or gliding, an engine counter would serve this purpose, but it is considered preferable to have a counter or recorder actuated by an anemometer for this purpose. In either case, actual distance over the surface will require correction for the wind velocity and direction.

BAROGRAPH.

Barographs are subject to the same general specifications as altimeters.

ANGLE OF ATTACK INDICATOR.

An angle of attack indicator should be dead beat, free from the effects of gravitation, and accurately respond to and indicate any change of the direction of flow of air to the supporting surfaces. It should be light, rugged, and its indications should be clearly legible to the pilot. It should be designed for attachment in advance of the wings on a tractor biplane and clear of the influence of the propeller or the body.

RADIATOR TEMPERATURE INDICATOR.

A radiator temperature indicator should be readily inserted in the top of the radiator and should clearly indicate the best operating temperatures. The thermometer should conform to best practice, and the entire instrument be sufficiently rugged to withstand reasonable vibration and shock.

GASOLINE FEED SYSTEM PRESSURE INDICATOR.

Where the gasoline feed is not gravitational, the indications of the pressure available must be accurate. The gasoline feed system pressure indicator must not be affected by vibration or change of temperature. It must have a good scale and a dead-beat action.

SEXTANT.

Sextants should be as light and small as possible commensurate with proper accuracy. A sextant for measuring the altitude of a heavenly body above a horizontal plane without the use of the sea horizon or an artificial horizon would be most desirable.

AIRPLANE DIRECTOR.

An airplane director for the mechanical solution of the course and distance made good, based on the course and speed of the aeroplane and the force and direction of the wind, is a desirable development.

REPORT No. 9.

NOMENCLATURE FOR AERONAUTICS.

By The NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS.

REPORT No. 9.

NOMENCLATURE FOR AERONAUTICS.

By The National Advisory Committee for Aeronautics.

INTRODUCTION.

For the information of those interested in aeronautics the following nomenclature has been prepared as a guide, with a view to eliminating the duplication of terms, the erroneous use of terms, and confusion of terms, and with a view to defining the principal terms which have come into use in the development of aeronautics. In the preparation of this nomenclature only those terms have been defined which are new and peculiar to this subject.

AERONAUTICAL NOMENCLATURE.

Aerofoil: A thin wing-like structure, flat or curved, designed to obtain reaction upon its surfaces from the air through which it moves.

Aeroplane: See airplane.

Aileron: A movable auxiliary surface used for the control of rolling motion—i. e., rotation about the fore and aft axis.

Aircraft: Any form of craft designed for the navigation of the air—airplanes, balloons, dirigibles, helicopters, kites, kite-balloons, ornithopters, gliders, etc.

Airplane: A form of aircraft heavier than air which has wing surfaces for sustentation, with stabilizing surfaces, rudders for steering, and power plant for propulsion through the air. This term is commonly used in a more restricted sense to refer to airplanes fitted with landing gear suited to operation from the land. If the landing gear is suited to operation from the water the term "Seaplane" is used. (See definition.)

Pusher.—A type of airplane with the propeller or propellers in rear of the wings.

Tractor.—A type of airplane with the propeller or propellers in front of the wings.

Air-speed meter: An instrument designed to measure the velocity of an aircraft with reference to the air through which it is moving.

Altimeter: An instrument mounted on an aircraft to continuously indicate its height above the surface of the earth.

Anemometer: An instrument for measuring the velocity of the wind or air currents with reference to the earth or some fixed body.

ANGLE:

Of attack.—The angle between the direction of the relative wind and the chord of an aerofoil, or the fore and aft axis of a body.

Critical.—The angle of attack at which the lift is a maximum.

Gliding.—The angle the flight path makes with the horizontal when flying in still air under the influence of gravity alone.

ASPECT RATIO: The ratio of spread to chord of an aerofoil.

AVIATOR: The operator or pilot of heavier-than-air craft. This term may be applied equally, regardless of the sex of the operator.

AXES OF AN AIRCRAFT: Three fixed lines of reference; usually centroidal and mutually rectangular.

The principal longitudinal axis in the plane of symmetry, usually parallel to the axis of the propeller, is called the fore and aft axis (or longitudinal axis); the axis perpendicular to this in the plane of symmetry is called the vertical axis; and the third axis, perpendicular to the other two, is called the athwartship axis (or transverse or lateral axis). In mathematical discussions the first of these axes is called the X axis, the second the Z axis, and the third the Y axis.

BALLONET: A small balloon within the interior of a balloon or dirigible for the purpose of controlling the ascent or descent, and for maintaining pressure on the outer envelope to prevent deformation. The ballonet is kept inflated with air at the required pressure, under the control of a blower and valves.

BALLOON: A form of aircraft comprising a gas bag and a car, whose sustentation depends on the buoyancy of the contained gas, which is lighter than air.

Captive.—A balloon restrained from free flight by means of a cable attaching it to the earth.

Kite.—An elongated form of captive balloon, fitted with tail appendages to keep it headed into the wind, and deriving increased lift due to its axis being inclined to the wind.

BANK: To incline an airplane laterally—i. e., to rotate it about the fore and aft axis. Right bank is to incline the airplane with the right wing down.

BANKING RUDDER: See Aileron.

BAROGRAPH: An instrument used to record variations in barometric pressure. In aeronautics the charts on which the records are made are prepared to indicate altitudes directly instead of barometric pressure.

BIPLANE: A form of of airplane in which the main supporting surface is divided into two parts, one above the other.

BODY OF AN AIRPLANE: A structure, usually inclosed, which contains in a stream-line housing the power plant, fuel, passengers, etc.

CABRÉ: A flying attitude in which the angle of attacks is greater than normal; tail down; down by the stern—tail low.

CAMBER: The convexity or rise of a curve of an aerofoil from its Chord, usually expressed as the ratio of the maximum departure of the curve from the chord as a fraction thereof. "Top Camber" refers to the top surface of an aerofoil, and "Bottom Camber" to the bottom surface; "Mean Camber" is the mean of these two.

CAPACITY:

Lifting.—The maximum flying load of an aircraft.

Carrying.—Excess of the lifting capacity over the dead load of an aircraft, which latter includes structure, power plant, and essential accessories.

CARRYING CAPACITY: See Capacity.

CENTER: The point in which a set of effects is assumed to be accumulated producing the same effect as if all were concentrated at this point.

Of buoyancy.—The center of gravity of the fluid displaced by the floating body.

Of pressure of an aerofoil.—The point on the chord of an element of an aerofoil, prolonged if necessary, through which at any instant the line of action of the resultant air force passes.

Of pressure of a body.—The point on the axis of a body, prolonged if necessary, through which at any instant the line of action of the resultant air force passes.

CHORD:

Of an aerofoil section.—A right line tangent to the under curve of the aerofoil section at the front and rear.

Length.—The length of the chord is the length of the aerofoil section projected on the chord, extended if necessary.

CONTROLS: A general term applying to the means provided for operating the devices used to control speed, direction of flight, and attitude of an aircraft.

CRITICAL ANGLE: See Angle, Critical.

DÉCALAGE: An increase in the angular setting of the chord of an upper wing of a biplane with reference to the chord of the lower wing.

DEVELOPED AREA OF A PROPELLER: A layout of the area of a propeller blade designed to represent the total area of the driving face, in which the elements of area are developed as if unfolded onto the plane of the drawing (necessarily an approximation on definite assumptions, as no true development of the helix can be made).

DIHEDRAL IN AN AIRPLANE: The angle included at the intersection of the imaginary surfaces containing the chords of the right and left wings (continued to the plane of symmetry if necessary). This angle is measured in a plane perpendicular to that intersection. The dihedral of the upper wing may and frequently does differ from that of the lower wing in a biplane.

DIRIGIBLE: A form of balloon, the outer envelope of which is of elongated form, provided with a propelling system, car, rudders, and stabilizing surfaces.

Nonrigid.—A dirigible whose form is maintained by the pressure of the contained gas assisted by the car-suspension system.

Rigid.—A dirigible whose form is maintained by a rigid structure contained within the envelope.

Semirigid.—A dirigible whose form is maintained by means of its attachment to an exterior girder construction containing the car.

DISK AREA OF A PROPELLER: The total area of the disk swept by the propeller tips.

DIVING RUDDER: See elevator.

DOPE: A general term applied to the material used in treating the cloth surface of air-plane members to increase strength, produce tautness, and act as a filler to maintain air-tightness; usually of the cellulose type.

DRAG: The total resistance to motion through the air of an air craft—i. e., the sum of the drift and head resistance.

DRIFT: The component of the resultant wind pressure on an aerofoil or wing surface parallel to the air stream attacking the surface.

ELEVATOR: A hinged surface for controlling the longitudinal attitude of an air craft—i. e., its rotation about the athwartship axis.

ENGINE, RIGHT OR LEFT HAND: The distinction between a right-hand and a left-hand engine depends on the rotation of the output shaft, whether this shaft rotates in the same direction as the crank or not. A right-hand engine is one in which, when viewed from the output shaft, looking toward the output end, the shaft is seen to rotate clockwise.

ENTERING EDGE: The foremost part of an aerofoil.

FINS: Small planes on air craft to promote stability; for example, vertical tail fins, horizontal tail fins, skid fins, etc.

FLIGHT PATH: The path of the center of gravity of an air craft with reference to the air.

FLOAT: That portion of the landing gear of an air craft which provides buoyancy when it is resting on the surface of the water.

FUSELAGE: See body.

GAP: The distance between the projections on the vertical axis of the entering edges of an upper and lower wing of a biplane.

GLIDE: To fly without power.

GLIDER: A form of air craft similar to an airplane, but without any power plant.

When utilized in variable winds it makes use of the soaring principles of flight and is sometimes called a soaring machine.

GLIDING ANGLE: See Angle, Gliding.

GUY: A rope, chain, wire, or rod attached to an object to guide or steady it, such as guys to wing, tail, or landing gear.

HEAD RESISTANCE: The total resistance to motion through the air of all parts of an air craft not a part of the main lifting surface. Sometimes termed "parasite resistance."

HELICOPTER: A form of air craft whose support in the air is derived from the vertical thrust of large propellers.

INCLINOMETER: An instrument for measuring the angle made by any axis of an aircraft with the horizontal.

KEEL PLANE AREA: The total effective area of an aircraft which acts to prevent skidding or side slipping.

KITE: A form of aircraft without other propelling means than the towline pull, whose support is derived from the force of the wind moving past its surface.

KITE BALLOON: See Balloon, kite.

LANDING GEAR: The under structure of an aircraft designed to carry the load when resting on, or running on, the surface of the land or water.

LATERAL STABILITY: See Stability, lateral.

LEADING EDGE: See Entering edge.

LEEWAY: The angular deviation from a course over the earth, due to cross currents of wind.
LIFT: The component of the force due to the air pressure of an aerofoil, resolved perpendicular to the flight path in a vertical plane.
LIFT BRACING: See Stay.
LIFTING CAPACITY: See Capacity, lifting.
LOAD, FULL: See Capacity, lifting.
Reserve (*or useful*).—See Capacity, carrying.
LOADING: See Wing loading.
LONGITUDINAL: A fore-and-aft member of the framing of an airplane body, or of the floats, usually continuous across a number of points of support.
LONGITUDINAL STABILITY: See Stability.
METACENTER: The point of intersection of a vertical line through the center of gravity of the fluid displaced by a floating body when it is tipped through a small angle from its position of equilibrium and the inclined line which was vertical through the center of gravity of the body when in equilibrium. There is, in general, a different metacenter for each type of displacement of the floating body.
MONOPLANE: A form of airplane whose main supporting surface is disposed as a single wing on each side of the body.
MOTOR: See Engine.
NACELLE: See Body.
NATURAL STABILITY: See Stability.
NOSE DIVE: A dangerously steep descent, head-on.
ORNITHOPTER: A form of aircraft deriving its support and propelling force from flapping wings.
PITOT TUBE: A tube with an end open square to the fluid stream, used as a detector of an impact pressure. More usually associated with a concentric tube surrounding it, having perforations normal to the axis for indicating static pressure. The velocity of the fluid can be determined from the difference between the impact pressure and the static pressure. This instrument is often used to determine the velocity of an aircraft through the air.
PROPELLER:
Developed area of.—See Developed area of a propeller.
Disk area of.—See Disk area of a propeller.
Right-hand.—One in which the helix is right handed.
PUSHER: See Airplane.
PYLON: A marker of a course.
RACE OF A PROPELLER: The air stream delivered by the propeller.
RIB: See Wing.
RIGHT (OR LEFT) HAND:
Engine.—See Engine.
Propeller.—See Propeller, right-hand.
RIGID DIRIGIBLE: See Dirigible, rigid.
RUDDER: A hinged or pivoted surface, usually more or less flat or stream lined, used for the purpose of controlling the attitude of an aircraft about its vertical axis when in motion.
SEAPLANE: A particular form of airplane in which the landing gear is suited to operation from the water.

Side slipping: Sliding toward the center of a turn. It is due to excessive amount of bank for the turn being made, and is the opposite of skidding.

Skidding: Sliding sideways in flight away from the center of the turn. It is usually caused by insufficient banking in a turn, and is the opposite of side slipping.

Skids: Long wooden or metal runners designed to prevent nosing of a land machine when landing or to prevent dropping into holes or ditches in rough ground. Generally designed to function should the wheels collapse or fail to act.

Slip: This term applies to propeller action and is the difference between the actual velocity of advance of an aircraft and the speed calculated from the known pitch of the propeller and its number of revolutions.

Soaring machine: See Glider.

Spread: The maximum distance laterally from tip to tip of an airplane wing.

Stability: The quality of an aircraft in flight which causes it to return to a condition of equilibrium when meeting a disturbance. (This is sometimes called "Dynamical stability.")

Directional.—Stability with reference to the vertical axis.

Inherent.—Stability of an aircraft due to the disposition and arrangement of its fixed parts.

Lateral.—Stability with reference to the longitudinal (or fore and aft) axis.

Longitudinal.—Stability with reference to the lateral (or athwartship) axis.

Stabilizer: See Fins.

Mechanical.—Any automatic device designed to secure stability in flight.

Stagger: The amount of advance of the entering edge of the upper wing of a biplane over that of the lower; it is considered positive when the upper surface is forward.

Stalling: A term describing the condition of an airplane which from any cause has lost the relative speed necessary for steerageway and control.

Statoscope: An instrument to detect the existence of a small rate of ascent or descent, principally used in ballooning.

Stay: A wire, rope, or the like, used as a tie piece to hold parts together, or to contribute stiffness; for example, the stays of the wing and body trussing.

Step: A break in the form of the bottom of a float.

Stream-line flow: A term in hydromechanics to describe the condition of continuous flow of a fluid, as distinguished from eddying flow where discontinuity takes place.

Stream-line shape: A shape intended to avoid eddying or discontinuity and to preserve stream-line flow, thus keeping resistance to progress at a minimum.

Strut: A compression member of a truss frame; for instance, the vertical members of the wing truss of a biplane.

Sweep back: The horizontal angle between the lateral (athwartship) axis of an airplane and the entering edge of the main planes.

TAIL: The rear portion of an aircraft, to which are usually attached rudders, elevators, and fins.
TAIL FINS: The vertical and horizontal surfaces attached to the tail, used for stabilizing.
THRUST DEDUCTION: Due to the influence of the propellers, there is a reduction of pressure under the stern of the vessel which appreciably reduces the total propulsive effect of the propeller. This reduction is termed "Thrust deduction."
TRACTOR: See Airplane.
TRAILING EDGE: The rearmost portion of an aerofoil.
TRIPLANE: A form of airplane whose main supporting surfaces are divided into three parts, superposed.
TRUSS: The framing by which the wing loads are transmitted to the body; comprises struts, stays, and spars.
VELOMETER: See Air-speed meter and anemometer.
VOL-PIQUÉ: See Nose dive.
VOL-PLANE: See Glide.
WAKE GAIN: Due to the influence of skin friction, eddying, etc., a vessel in moving forward produces a certain forward movement of the fluid surrounding it. The effect of this is to reduce the effective resistance of the hull, and this effect, due to the forward movement of the wake, is termed the "wake gain."

In addition to this effect the forward movement of this body of fluid reduces the actual advance of the propeller through the surrounding medium, thereby reducing the propeller horsepower.
WARP: To change the form of the wing by twisting it, usually by changing the inclination of the rear spar relative to the front spar.
WINGS: The main supporting surfaces of an airplane.
WING LOADING: The weight carried per unit area of supporting surface.
WING RIB: A fore and aft member of the wing structure used to support the covering and to give the wing section its form.
WING SPAR: An athwartship member of the wing structure resisting tension and compression.
YAW: To swing off the course about the vertical axis, owing to gusts or lack of directional stability.

Angle of.—The temporary angular deviation of the fore and aft axis from the course.

REPORT No. 10.

MUFFLERS FOR AERONAUTIC ENGINES.

By PROF. H. DIEDERICHS and PROF. G. B. UPTON,
Of Cornell University.

REPORT No. 10.

MUFFLERS FOR AERONAUTIC ENGINES.

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Of Cornell University.

I. THE PROBLEM.

The necessity for muffling the exhaust of airplane engines is hardly open to argument. The objects in view are the minimizing of noise to delay detection in military service, to protect the general public, particularly those living near aviation fields, and lastly to give the operator a better chance to know what the rest of his power plant is doing. The last point is perhaps even now of little importance, as an exhaust pipe long enough to end behind the operator is quite enough to make the exhaust noise less prominent than some other rackets.

A study of the general problem of silencing the airplane power plant, not only in the laboratory but also by means of observing airplanes in a large number of flights, has led to certain conclusions, none of which are, however, new. In the first place the exhaust noise is not the only disturbance to be dealt with, although perhaps the most important, because the staccato barks of open exhaust carry to greater distances than the other attendant noises. It is, however, not a matter of great difficulty to so far suppress these barks that the exhaust noise ceases to be the most prominent in relation to some others. As a matter of fact, a simple pipe of sufficient length will do this for the high-speed multicylinder engines, and we understand that some American and German planes are using this scheme. It serves at least to protect the operator, even if it does not go a great way toward actually suppressing the pulsations as far as an observer at a distance is concerned. The very fact that the impulses follow so rapidly upon one another seems to make the problem of taking off the "bark" easier, for we found it much harder to muffle single-cylinder slow-speed engines.

Assuming, however, that a successful device for completely muffling the exhaust can be found, we should still have to deal with other noises, such as the hum of the propeller, the singing of gears, and the rattle of the valve gear. It will be admitted that all of these sources of noise can be minimized, but elimination does not seem to be in the realm of possibility.

On the 8-cylinder engine used for our last experiments the propeller of the fan brake caused a deep, more or less musical note, which appeared to come from the crank case. This noise disappeared when the blades were removed from the fan arm, and the engine was operated at speed under its own power, swinging only

the arm. The same sort of humming note can be identified in connection with planes in flight at considerable altitudes and distances. To silence this disturbance presents a problem on which at present the writers have no suggestions, except that slower speed (geared) propellers might help.

Another source of noise is in the valve gear. In the case of the engine under test this consisted in a sort of rattling hiss at high speeds. It can be easily identified when the observer is close by. In planes of flight at some distance from the observers the noise would appear to be drowned in the exhaust roar and in the hum of the propeller. In any case this disturbance can be minimized by accurate adjustment. But it is difficult to see how the valve slap can be entirely eliminated.

The last source of noise is in the gears. This can be partly suppressed at least by the use of spiral gearing and by accurate machine work and mounting.

These four sources of noise are the principal ones requiring attention. We would place them in order of importance: (*a*) Exhaust noise, (*b*) propeller noise, (*c*) valve-gear noise, (*d*) gear noise. We believe that it is most important to suppress the exhaust noise, because its staccato barks will undoubtedly advertise the rising of a plane sooner than the other three by reason of its greater carrying power. But the problem of the other noises remains; and we are further of the opinion, based on our experience in the past year, that the exhaust noise can be so far suppressed with comparatively simple means that it forms the smallest source of the disturbance of the four. We will not venture to predict complete suppression. Any muffler construction in connection with its manifold will have to take in some one of its parts the full force of the original blow, and since lightness of construction is one of the requirements calling for thin walls the chances are that there will always be more or less of a pulsating roar, at least near the engine. We have so far not reached the stage of considering this part of the problem.

Confining our attention now to the particular problem in hand, the silencing of the exhaust, a successful device will have to meet three requirements: (*a*) Satisfactory suppression of noise with least back pressure, (*b*) lightest possible weight, (*c*) greatest durability. For the last year we have confined our attention to the first of these, believing that the other two could be successfully met if the first requirement were satisfied.

II. PRESENT DEVELOPMENT OF MUFFLING DEVICES.

The state of perfection at present reached in the muffling of auto-engines is well known. As far as this problem is concerned, it may be considered solved as regards suppression of noise. Not a great deal of scientific data are available. Some tests were carried on at the University of Michigan, an abstract of the report being published in the Horseless Age for May, 1915. Five types of mufflers were tested and investigated as to back pressure, horsepower loss, and muffling ability. Of the five, the one given the highest rank on all three counts has the construction shown in figure 1. The engine used was a nominal 25 horsepower automobile engine (Hudson 6–54, $4\frac{1}{8}$ by $5\frac{1}{4}$ inches), the test speed ranging from 750 to 1,300 revolutions per min-

ute. At the latter speed the brake horsepower reached 40. The muffler weighted 14.5 pounds, which is equivalent to 0.36 pound per horsepower, based on the maximum power, and had a volume capacity of 847 cubic inches, which is approximately nine times the cylinder displacement. All of the other mufflers weighed more, so that 0.36 pound per horsepower may perhaps be considered the present mini-

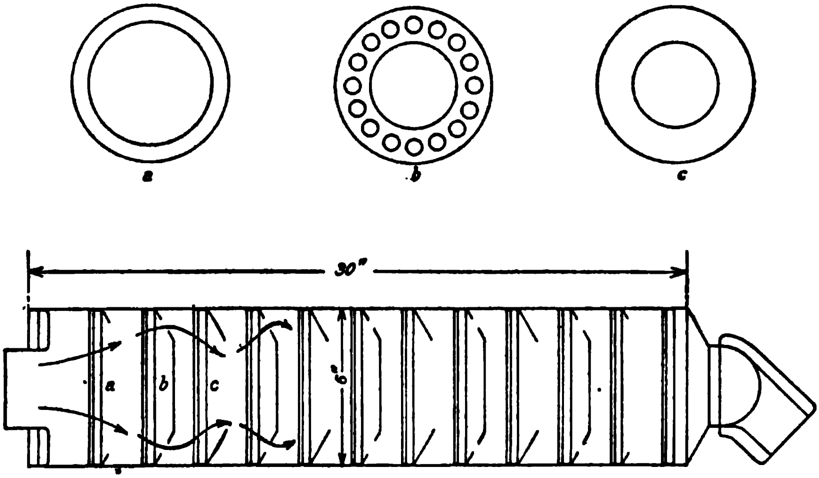

FIG. 1.

mum in automobile practice. This is a feature, however, of not as great importance as it would be in airplane practice. This muffler showed a back pressure of only slightly over 1 pound at the maximum speed, the loss of horsepower being only 1.4 per cent at the maximum. For automobile practice this must be considered an excellent showing.

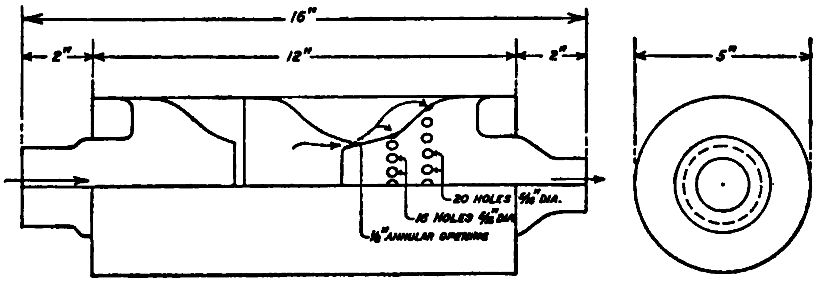

FIG. 2.

We were fortunate enough to obtain the loan of two mufflers especially designed for an 8-cylinder V-type engine and commercially manufactured. The smaller one of these mufflers is intended for a single cylinder and is 5 inches in diameter by 12 inches long. It has the construction shown in figure 2. The larger one, intended for four cylinders, is 5 inches in diameter and 28 inches long. The inter-

nal construction is probably made up of a multiplication of the elements of the smaller muffler. Both of these mufflers were tested by connecting them directly to the ends of the side manifolds by means of slip joints. Speed changes were noted by forcing the mufflers on and pulling them off by hand. This method of testing puts a heavier load on the smaller muffler than it is designed for, but since we did not have eight of them this was the only method available.

The tests on the smaller mufflers resulted as follows:

Throttle position on scale.	Back pressure, "Hg mufflers.		Corrected revolutions per minute, mufflers.		Back pressure increase, "Hg.	Speed drop.	
	Off.	On.	Off.	On.		Revolutions per minute.	Per cent.
4	0	0.25	933	933	0.25	0	0
5	0	.55	1,071	1,071	.55	0	0
8	0	1.90	1,257	1,143	1.90	7	0.52

Throttle position on scale.	Brake horsepower, mufflers.		Per cent horsepower loss.	Brake mean effective pressure (pounds per square inch), mufflers.		Loss of brake mean effective pressure, pounds.
	Off.	On.		Off.	On.	
4	28.8	28.8	0	48.6	48.6	0
5	43.4	43.4	0	64.0	64.0	0
8	69.8	68.6	1.5	87.7	86.8	0.9

The larger muffler gave the following results:

Throttle position on scale.	Back pressure, "Hg mufflers.		Corrected revolutions, per minute, mufflers.		Back pressure increase, "Hg.	Speed drop.	
	Off.	On.	Off.	On.		Revolutions per minute.	Per cent.
4	0.01	0.64	928	928	0.63	0	0
5	.025	1.5	1,066	1,060	1.48	6	0.51
8	0	4.0	1,268	1,240	4.0	28	2.24

Throttle position on scale.	Brake horsepower, mufflers.		Per cent horsepower loss.	Brake mean effective pressure (pounds per square inch), mufflers.		Loss of brake mean effective pressure, pounds.
	Off.	On.		Off.	On.	
4	28.3	28.3	0	48.1	48.1	0
5	42.8	42.1	1.5	63.4	62.7	0.7
8	72.1	67.4	6.6	89.7	85.8	3.9

It will be noted from these figures that, in spite of the unexpected load, the smaller muffler gives the better results. As a matter of fact, the horsepower loss at rated output for the larger muffler is prohib-

itive. On the other hand, several observers judged that the larger muffler more effectively quieted the exhaust noise. The two, however, are so close together regarding this point that it became difficult to judge of the difference in connection with the other noises. Our conclusion is that both mufflers are good with respect to quieting and that the greater efficiency of quieting in the larger muffler is bought at too great an increase in the back pressure. We have no hesitation in saying that the smaller muffler is as good a solution of the problem as we have yet seen.

III. THE EXPERIMENTS.

Experiments with devices constructed by us were carried out partly on a single-cylinder slow-speed machine, partly on a 60-horsepower 4-cylinder Maxim engine, and lastly on an 8-cylinder Curtiss engine.

The principle underlying the action of muffling is simple. At the moment of opening of the exhaust valve the pressure conditions are such that the gases issue at velocities of approximately 2,000 feet per second. The problem is to reduce this velocity below that of sound (1,100 feet per second) without causing undue back pressure. The bark of the open exhaust is due to the issuing of the gases at velocities higher than that of sound, and the main disturbance is suppressed as soon as the velocities are brought below 1,100 feet per second. The means at hand to accomplish this are: (*a*) Cooling of the gases to reduce volume, (*b*) gradual expansion, (*c*) internal friction and eddy currents in the gas, and (*d*) frictional resistance between gases and containers and baffles. Of these the first mentioned is practically negligible, as the degree of cooling can not be great in the time available.

To bring into play the other three means would require a construction having the following essentials: (*a*) An entrance chamber several times the cylinder volume, to allow of the unrestricted transfer of the gases from the cylinder to this chamber, for the purpose of preventing undue back pressure, and (*b*) one or more expansion chambers so provided with baffles as to break up the gas currents in such a manner as to cause decreasing velocity by means of both expansion and friction.

As far as application to the engine is concerned, three solutions are possible. The first is to use individual mufflers for each cylinder. This scheme at first sight has a good deal in its favor, but upon analysis several prohibitive disadvantages will appear. In the first place, there is no doubt that, say, 8 small mufflers will weigh more than 2, each taking care of 4 cylinders. In the case of the commercial muffler above mentioned, the weight relation is 15 pounds for 4 individual mufflers to 6 pounds for the single muffler doing about the same work. Further, the advantage that a 4-cylinder manifold will in itself act partly as a muffler is lost, and we would have the individual bark of each cylinder to deal with. And, finally, where the scheme had been tried it was found very difficult to properly stay so many mufflers as to prevent dangerous vibrations.

The second scheme is to combine manifold and muffler, i. e., to internally construct the manifold to convert it into a complete muffler. This scheme also looks good at first sight; but in order to provide sufficient volume a manifold so constructed would be of large

diameter, since the lateral distance between cylinders is restricted, and it is a question whether it is desirable to place so large a heat-radiating surface next to the cylinders and the structural members of the plane. The question of adding weight at that height from the base to the side of the cylinders is also of importance with relation to possible excessive vibration. We tried one scheme of this kind on the Maxim engine, as below noted, but with doubtful success.

The third scheme is to use a regular manifold and to connect this by means of flexible hose to the muffler proper. This allows of any convenient placing of the muffler with reference to engine and to operator. The length of exhaust hose is of no importance, consistent only with low back pressure, and, given this, a considerable length of hose or pipe is a positive help to the muffler. We believe on all counts that this combination is the best solution.

The first experimental construction embodied the idea of making the entrance space a centrifugal whirl chamber in which the gases were to lose part of their kinetic energy by mutual interference before passing out through holes or slots in a central pipe. It was made up out of a 4-inch tee, the side branch of which was capped, and the cap then bored and threaded for the 1½-inch exhaust pipe, of a 6-horsepower oil engine. The opening from this pipe was placed eccentrically in the cap, so that the gases entered the 4-inch tee tangentially. One of the straight-run openings of the tee was plugged, while the other was bushed to receive a 1½-inch pipe. The pipe could be extended varying distances into the tee by a long thread. Tests were made with this central pipe not perforated in any way, but open at the end. The best results were found when this pipe extended to within ½ inch of the opposite plug. Later the end of the central pipe was plugged and the pipe perforated with holes, a second one was then tried perforated with slots. In these cases the gas, after whirling around in the chamber, found its way into the central pipe through the holes or slots and so on out. All of these devices were only moderately successful and did not seem to promise much.

It was then thought desirable to improve the entrance conditions to the whirl chamber by gradually broadening the entrance pipe, thus introducing the gas tangentially in a wide band. Figure 3 shows the construction. Three concentric central pipes, a 4-inch, a 3-inch, and a 2-inch were used, the latter being open to the air at both ends. The central pipes were slotted, the 4-inch and 3-inch pipes as in figure 3–a, the 2-inch pipe as in figure 3–b. It was found that the direction of the slots in the inner pipe caused the gas to move out of one end of the pipe, creating a distinct suction on the other end. This device showed up much better than the crude first construction. It was estimated to cut out 80 per cent of the noise. Back-pressure readings were not taken, as we were as yet mainly interested in noise reduction.

The success of this device on the particularly vicious bark of the oil engine on which it was used led us next to construct a combined manifold and muffler of this type for the Maxim engine. The main features of this muffler were: An expanding, flattened nozzle from each cylinder to lead the gas tangentially into the shell, a common annular chamber between the largest inserted pipe and the shell into

which the exhaust from all cylinders first entered, a series of four pipes 2, 3, 4, and 5 inch, with perforations so arranged that the gas must first pass through the wall of the 5-inch pipe in a slanting direction, and having attained a certain velocity in this direction must turn and pass through the 4-inch in the opposite direction because of the slotted openings. Another turn was necessary to pass through the 3-inch, and finally through the 2-inch to the atmosphere.

We did not succeed in getting a very good idea of the action of this manifold muffler, as the Maxim engine, which had been loaned us, was recalled. The trial run made promised fairly well, but the end joints between the pipe were not tight and considerable gas escaped. As built, with a cast-iron jacket, this muffler proved exceedingly heavy.

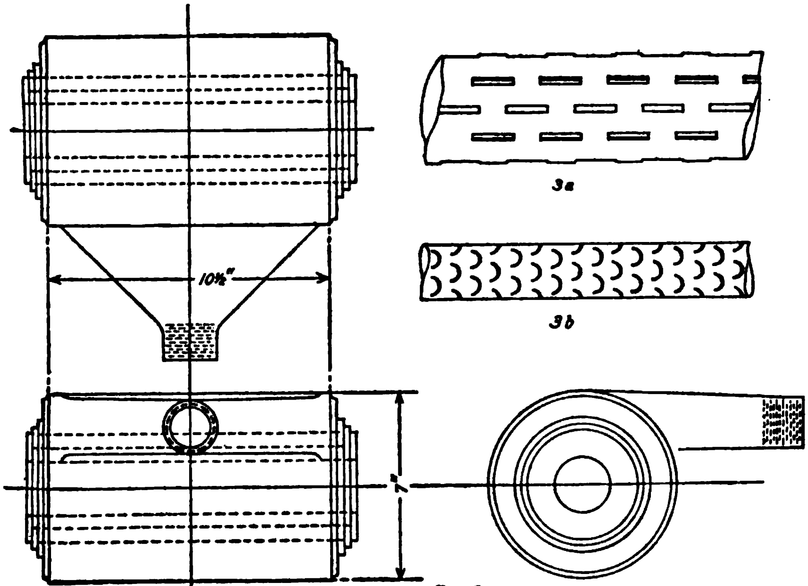

Fig. 3.

We have not done anything more with the manifold mufflers, but intend to try out one or two other ideas, which, however, have so far reached only the design stage.

The last work was done on an entirely different type from that above described. The underlying idea in this type is to provide an ample receiving chamber, and then as the gases work toward the outlet, to provide gradually increasing resistance, until the pulsations are toned down and the gas issues in streams of fairly constant velocity at speeds below that of sound. This should substitute for the bark a hiss like that of escaping steam of low pressure. It might be pointed out that the well-known Maxim muffler is of this general type. Only in this muffler the circular receiving chamber is followed by an annular space surrounding the former, which space is packed with baffle plates of spiral form. The gases here lose velocity by internal friction and surface friction. No attempt is made to utilize the idea of a gradually increasing resistance to the flow toward the outlet.

The scheme was tried out on the 8-cylinder Curtiss engine. Two manifolds of light-weight steel were cross connected by another manifold, so that we finally had a single discharge and only one experimental muffler had to be built. The construction of this is shown in figure 4.

We adopted for this muffler the prismatic form for two reasons. In the first place, it is easier to construct than the circular form; and secondly, we believe that this form may have some advantages over the circular form for stowing away on an airplane. The essential features are as follows: Gradually expanding entrance nozzle A, a receiving chamber B, two expanding and retarding chambers C and

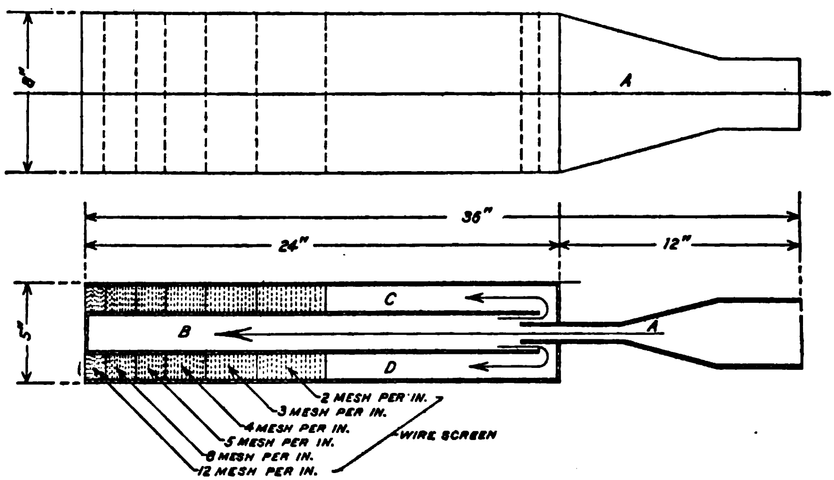

FIG. 4.

D. About half of the two expansion chambers are filled with closely packed wire gauze of decreasing mesh, in the following order going toward the outlets:

	Layers.
$3\frac{1}{2}$ inches of 2 meshes per inch	28
$2\frac{1}{2}$ inches of 3 meshes per inch	26
2 inches of 4 meshes per inch	24
$1\frac{1}{2}$ inches of 5 meshes per inch	18
$1\frac{1}{2}$ inches of 8 meshes per inch	20
1 inch of 12 meshes per inch	25

This muffler was connected to the outlet of the cross manifold by a short piece of flexible metallic hose and in parallel with a quick-closing gate valve. By this means the exhaust could be instantly changed from muffler to open air and back again. An electric tachometer, carefully calibrated, was used to note changes in speed, and the back pressures were observed by means of mercury manometers connected to the side manifolds near their connection to the cross manifold.

Trials with this muffler showed the following:

(*a*) The application of the side manifold and of the cross manifold alone served to tone down the barks considerably. The back

pressure observed with only the side manifolds was negligible and with the cross manifold showed about 0.3-inch Hg. at rated output of 70 horsepower.

(b) The application of the muffler raised the back pressure only about 0.1-inch Hg., which is a very good result. The power loss is negligible.

(c) As far as muffling is concerned, three observers judged that the exhaust noise was cut out to the extent of about 50 per cent.

We believe that the muffling efficiency of this construction can be improved, and we have already started to work out an improved design. The virtual absence of back pressure is the most encouraging feature. Objection has been made to this design on the score of carbon clogging of the wire gauze. Only a service run of some hours' duration can prove this point.

At present we have not used any quantitative scheme of judging degree of noises, but have depended upon several independent observers. This scheme is not wholly successful on account mainly of the other noises present besides the exhaust. As a matter of fact, to get any idea at all of this matter in connection with the Curtiss engine, it became necessary to extend the pipe through a window and to place the muffler outside of the building. In the University of Michigan tests, above quoted, besides using independent observers, a telephone was used, the observer in a room some distance away noting the distance between himself and the telephone at which he failed to distinguish the exhaust noise. The receiver was placed near the engine. What such a scheme would show in our case is problematical, but we intend to try it out the coming year. We wish gratefully to acknowledge in this connection the active help of Profs. V. R. Gage and C. A. Peirce, of the Sibley College faculty, and the assistance and facilities supplied by the Thomas Aeromotor Co., of Ithaca, N. Y., and the Curtiss Aeroplane & Motor Corporation, of Buffalo, N. Y.

Further experiments will be made on this type of muffler construction and the determination of the laws affecting feed back pressure power loss are already being investigated and will be the subject of a future report.

REPORT No. 11.

(In Seven Parts.)

CARBURETOR DESIGN—A PRELIMINARY STUDY OF THE STATE OF THE ART.

By CHARLES EDWARD LUCKE,
Professor of Mechanical Engineering,

Assisted by FRIEDERICH OTTO WILLHÖFFT,
Assistant Professor of Mechanical Engineering.

COLUMBIA UNIVERSITY, NEW YORK CITY.

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REPORT No. 11.

PART I.

By Charles E. Lucke.

INTRODUCTION—NATURE OF THE PROBLEM AND SCOPE OF THE PRESENT CONTRIBUTION.

Any effort to improve the gasoline engine and to perfect it for use, in aeronautic, marine, and land transportation service, must proceed along a series of more or less parallel coordinate lines of attack, each concerned with some one independent phase of the problem, after a general review has indicated the nature of these subsidiary problems and their relations. Such a general review with special reference to aero engines has already been made and formed the subject matter of the report of last year. In addition to the specific problems of engine design proper, involving arrangement of parts, selection and treatment of materials, and determination of best diemnsions for strength or life on the one hand and large mean effective pressures with high thermal efficiency at high speeds on the other, there is another group concerned with what might be termed the engine auxiliary functions. These latter include ignition, lubrication, cooling, and last, but most important of all, carburetion. It is most important because it is concerned with the making of suitable mixtures, without which the engine can not be a success no matter how perfectly the other phases of the engine problem may be worked out. It bears the same relation to the gasoline engine as steam making does to the steam engine, and the carburetor, with its connections by which the result is attained, is just as important to the former as is the steam boiler and its connections to the latter. This being the case, it is logical and proper that this the second report, and the first one following the general review, should be concerned with the carburetor and the problems of its design. The complexity of the problem of carburetor design, from the scientific engineering standpoint as distinguished from the empiric cut and try one, can hardly be overrated, and the difficulties involved are realized only by those familiar with the question by reason of experience and extended study. It involves not only many unknown facts and relations of the physics of flow of this class of liquids in small passages and of air at variable rates through every conceivable shape of duct and orifice within certain limits of size, but it also requires the crossing of the borderland of knowledge on the physical chemistry of these complex fuels, their vapors, and vapor air mixtures; fuels which are solutions of many and variable constituents, all of them having tendencies under

certain conditions to polymerize. In addition to these difficulties of a physical-chemical sort, there are involved two other groups, the first being the usual one of structural design, and the second that of definition of the object to be attained. With reference to the latter it must be admitted that there is no convincing experimental proof avaliable from engine tests to definitely establish just what sort of mixtures give the best results in engines; whether, for example, they should be constant or variable in proportions of air to fuel, and whether also they should be dry or wet, and if the latter, how much moisture is permissible and in what form. To be sure, opinions and deductions of some value can be based on indirect observations and on certain principles, but works of importance should be based on proved facts and not on opinions or deductions. Pending the establishment of the required physical-chemical data and the specifications of suitability of mixtures from the engine standpoint, both of which must constitute a separate series of investigation, the problem of carburetor design may be approached with some profit from the qualitative side.

Design of any appliance or machine must be undertaken qualitatively before any quantitative work is warranted, the former being concerned with the form and arrangement of the parts and the latter with their dimensions. Qualitative design, the fixing of the nature and form of the several necessary structural elements and their mutual relation or arrangement, must satisfy ten independent sorts of requirements—first, functional, and second, constructional. With reference to the former it is clear that to make the apparatus work there must be provided certain parts suitably arranged and the selection of such forms and arrangements of parts as would seem to promise the sort of action or function desired, is termed invention when the same thing has not been done before in the same way, otherwise it is merely the first phase of qualitative design. The second or constructional requirement for qualitative design imposes a limit on the first, dictated by the tools and processes of the shop. However nice and proper an appliance or machine scheme may be from the functional standpoint, it is obviously of no value if it can not be constructed and of little value if the construction is difficult, so as to involve excessive cost, inaccuracy, or some other element of unsuitability.

Quantitative design, the determination of proper dimensions, for the parts as selected and arranged, must also meet two independent requirements, or rather there are two sets of dimensions that must be separately determined because they have different objects. The first phase of quantitative design must fix those dimensions that are concerned with functional operation and directly supplement the selection of form and relation of structural elements, so that not only will the sort of result desired be attained, but also in just the right degree. The second step in the whole series fixes those dimensions of the parts that insure, with due reference to the materials, suitable strength and stiffness to resist rupture and undue deflection, respectively, under stress, and that insure suitable life to parts subject to destruction by wear or corrosion, for example.

Applying these general principles to the case of carburetor design, the first phases of both the qualitative and the quantitative design

are of controlling importance, both of the second phases dwindling to almost negligible quantities in comparison. For example, the second phase of quantitative design, the fixing of dimensions for strength and life, is almost, if not quite, eliminated by the fact that the parts of carburetors are subjected to no stresses that can not easily be resisted by the thinnest metal that can be cast, and that, so far as life is concerned, there is no corrosion with the brasses and bronzes in use. While there is some wear in those carburetors that have moving parts and some permanent set in springs, it also is true that good carburetors need have neither wearing parts nor springs. Again, the second phase of qualitative design, which imposes shop limitations on form and arrangement, requires no special treatment for carburetors over any other device or small manufactured metal product made mainly or wholly of cast metal with some rough and some accurate machining, involving only light cuts and short operations easily carried out with small tools of standard form with special jigs and fixtures or with special tools.

It appears, therefore, that an investigation of carburetor design must be concerned almost entirely with the first phases of both qualitative and quantitative design, the selection of these schemes of form and arrangement of parts that promise the right sort of functioning and results, and then dimensioning the parts so they will produce the desired kind of result in the required degree. These two steps might well be called qualitative functional design and quantitative functional design, respectively.

There are two good reasons why qualitative functional design should be undertaken before the quantitative—first, because the necessary physical data for the latter have never been determined, only a few isolated facts being available, and second, because the determination of dimensions must necessarily follow a decision on form, or otherwise the more that form alternatives can be reduced to a minimum, the less is the variety and scope of the pertinent physical data required for application to them.

This report is concerned almost exclusively with an analysis of the question of qualitative design, not only because it is logically the first step to undertake but also because its scope is so very wide and the amount of available material requiring review so large as to have taken up all of the time available.

Quantitative design has been approached but not actively attacked; only so much has been done in this direction as to point out the need of thorough investigation by showing the importance and the present lack of exact data.

Qualitative functional design of carburetors must begin with an examination of alternative processes of carburetion, and a selection of one or more such processes as seem promising must be made before any attempt is made to scheme out the form and arrangement of the parts that together shall constitute the carburetor. Carburetion as a process is in the broad sense essentially the same as humidification, the former dealing originally only with the hydrocarbon products of petroleum but now with any liquid fuel including the alcohols, the latter with water, and both with vaporization of the liquid in contact with air, the vapors and the air mixing more or less homogeneously. The thermodynamic laws of such vapor-air mix-

tures as result from carburetion or humidification are pretty firmly established, and the most important of these, with reference to the present object, is that group relating the partial pressures of the vapor and the air in the mixture to the proportions of vapor and air and to the respective molecular weights. In accordance with these relations, a mixture of vapor and air in any desired proportions can be obtained by maintaining an intimate contact between the liquid and the air until such time as saturation results by the building up of the partial pressure of the vapor in the mixture to a value equal to the pressure of saturated vapor corresponding to the temperature. Thus the proportions are determined by the vapor pressure-temperature law of the liquid, by the actual conditions of contact or intimacy between the two, and by the temperature mixture during the time of contact. Of these three factors one is a physical property of a given liquid and the other two represent variables of use, and are subject to control if the apparatus is suitably designed. The vapor-pressure curves of the more common simple liquids have been determined, and for them these principles point directly to a simple and highly effective process of carburetion in definite predetermined proportions, the process being to maintain for sufficient time a close and intimate contact of the air and the liquid, such as may be done by blowing air over, bubbling it through the liquid, spraying the liquid in the air, or stirring and heating the two in a chamber, meanwhile keeping the temperature constant at the value required by the vapor pressure-temperature curve to give the desired proportions.

Such a process of carburization may properly be called evaporative because the proportions are fixed by the evaporative conditions. The liquid vaporizes, and vapor is added to the air until equilibrium is established between the vapor pressure of the liquid, and the partial pressure of the vapor in the mixture in contact with the liquid. This evaporative process of carburization to given proportions is almost ideal where it is feasible, but unfortunately its value is confined entirely to the simple liquids that have definite vapor pressure-temperature relations and the same relations for every part of the liquid. The only liquids that satisfy this condition are those that are single chemical compounds and among the fuels these are benzol and the pure alcohols, the more common fuels such as the impure alcohols or alcohol-water solutions, and all the products of petroleum, including not only the light but the intermediate constituents, do not satisfy the condition for proper evaporative carburization in given proportions by the simple evaporation process. These latter liquids fuels are solutions of many constituents one in the other, each constituent to be sure is a simple hydrocarbon with fixed physical properties, but the solution has variable physical properties. The presence of one substance in solution in another, affects its vapor pressure in a fairly well-known way, but there is no means of predicting what is the resultant of 10 such, each affecting the other. Physical chemistry has not advanced far enough to answer such a question, and it is doubtful if the answer would be of much value even if it could be found in the absence of equally definite, simple, and practical analytical means of identifying and evaluating the separate hydrocarbon constituents of such solutions as the gasolines and kerosenes, which organic chem-

istry so far has failed to discover. From the practical carburetor standpoint enough is known to definitely condemn the simple evaporative proportioning process without such scientific data, because it is clear that those constituents that have the highest vapor pressures will exist in the vapor air mixture in larger proportions to those that have low vapor pressures, than they did originally in the liquid mass, and that, as evaporation proceeds there will be a fractionation that leaves the heavy constituents behind. The mixture proportions in such cases will be fixed as much by the ratio of constituents in the liquid as by the vapor pressure of any one—by the intimacy of air contact or by the temperature—but the ratio of constituents in the liquid varying as it does as evaporation proceeds, the proportions of vapor to air in the mixture can not possibly be controlled automatically by any simple and practical means.

The condemnation of the evaporative means of proportioning as a carburetion process for engine use for all liquid fuels that fractionate at once removes from consideration a very large number of older carburetors designed for and used largely in connection with the manufacture of illuminating or fuel gas for pipe distribution and confines attention to a newer group of carburetors in which the proportions of air to fuel are subject to mechanical control and are quite independent of the constituents of the fuel or their vapor pressures.

Mechanical proportioning is an essential element of any practical carburetion process where complex fuels, like the petroleum distillates, are to be converted into vapor air mixtures in controlled proportions for introduction into an engine cylinder; but, of course, mechanical proportioning does not of itself constitute a carburetion process except under one condition. If the vapor pressure of the fuel, or, rather, of its heaviest constituent, be high enough, then mere introduction of the fuel into the air, especially if both be flowing through passages that produce eddy mixing currents, will result in immediate vaporization and the formation of the desired mixture. All the older gasolines of 76° Baumé and upward had this property, so for them a mechanical proportioner that feeds a measured amount of gasoline into an air stream does in reality constitute a proportioning carburetor. The present-day gasolines, ranging but little above 60° Baumé, and in some cases lower, have some constituents so heavy and with vapor pressures so low as to require either special spraying and stirring elements or heaters to produce a suitable homogeneous mixture, the making of which constitutes carburetion. Nevertheless such proportioning devices are also termed carburetors, even though vaporization is not complete, because they produce mixtures on which engines can be operated, and since the proportions are established by a sort of metering action of the fuel by the flowing air, and not by the vaporizing properties of the fuel, they have been named "proportioning flow carburetors" in this report.

For all gasolines, kerosenes, or other petroleum distillates, and any other complex fuel to be used in engines, proportioning flow carburetion processes must displace the older evaporative processes of the gas industry, so attention must be concentrated on the various ways in which the air flowing toward an engine cylinder may be made to proportionately meter, receive, and become mixed with the amount

of fuel it can support in explosive combustion quite independent of just what degree of vaporization or just what proportions will work best in a given engine on the assumption that these are independent variables.

The pure case of proportionate flow carburetion is that in which the air flow directly, without the medium or interposition of any connecting mechanism, does of itself induce or produce the fuel flow in amount always proportionate to the amount of air, simultaneously mixing the two more or less actively with or without the addition of heat. This process depends upon the laws of flow of air and of liquid fuel, relating rate of flow to pressure drop or flow head, and, in general, it assumes that the suction stroke of an engine piston establishes a vacuum of some degree in every portion of the air entrance passage, which vacuum varies regularly with the quantity of air that will flow under its impelling influence. It also assumes that if from a supply of fuel at a constant hydraulic head a connection be led to a fuel nozzle somewhere in the air passage, the static head with reference to the nozzle being ideally zero, then no fuel will flow unless air is also flowing, because of the common vacuum relation, and fuel flow will increase with air flow as the vacuum increases. For such double flow to be truly proportionate and in constant ratio it is clear that both the liquid and the air flow must follow similar physical laws and that the weight of each must bear the same algebraic relation to the vacuum that is responsible for the flow. In the absence of a pair of air and fuel passages of such form and relative disposition as would have similar flow laws, then some means of automatic correction of the proportions become necessary to restore the desired ratio and to maintain it, no matter how the rate of flow may vary, so as to satisfy the demands of engines operating at variable speed and load.

Between these two basic processes of carburetion—the "evaporative" and the "proportioning flow"—there may be found a series of minor alternatives, or special modifications, some of them standing more or less apart and others lying midway between and involving both to an equal degree. As an example of the latter a truly evaporative carburetor of the tank and wick type may be modified by feeding fuel to the wick by a proportionate-flow device instead of allowing the wick to pick up and feed fuel from the tank by capillarity. Evidently an apparatus of this sort might be classed under either process. If the proportionate-flow feeder were so regulated that no fuel accumulated on the wick or in the wick chamber, then evaporation does not fix the proportion, but the proportionate feeder does, and the device is a proportionate-flow carburetor. On the other hand, if the proportionate-flow feed delivered an excess of fuel over what could be carried off by the air passing the wick, some fuel would accumulate on or about the wick, and the proportions of the delivered mixture would be fixed by the evaporative and not by the proportionate-flow elements, and the device would be an evaporative carburetor. Fortunately, such cases as this are rare, or there would be more confusion than now exists. There is generally no difficulty in interpreting the action of a given apparatus, or, to state it otherwise, there are very few cases where the basis or principle of proportionality depends on the rate of feed, the adjustment or other operating conditions, within the working range.

Another sort of mixed process is that of direct injection of fuel by a pump into the air, the pump being driven by the pulsations of the air pressure in the intake passage or by the engine directly, and the delivery of fuel being made into the air on its way to the cylinder through the intake passages or directly into the cylinder after the air has entered. These are not regarded as proportionate-flow processes, because in general there is no definite proportion maintained; but also because the air-flow rate is not of itself responsible for the quantity of fuel fed. If a constant-speed engine cylinder took the same amount of air every stroke and a pump, driven from the air pulsations or from the engine, delivered the same amount of fuel at the same time, then the fuel and air quantities would clearly be in proportion, fixed by the displacement of the main piston and pump plunger, respectively, with corrections for volumetric efficiency. While this constitutes one series of mechanical proportioning means, the cases are special, as also is the engine-operative condition of constant speed and load, to which they are applicable. All direct-injection engines with or without compressed-air sprays constitute a quite independent class, characterized by mixture making directly in the cylinder and have practically nothing in common with the carburetor class of engines making mixtures externally. Pump deliveries to carbureting chambers in the intake passages, when the pump is driven by the engine, or, in fact, in any way except by the movement of the entering air, are excluded from the proportionate-flow class because the flow is not essentially proportionate. They constitute an additional class between the truly proportionate-flow and the direct-injection classes.

When the air flow actuates an air motor equivalent to an air meter and this motion in turn actuates a fuel pump, then the combination is truly a proportionate-flow carburetion system, operating on a constantly metering volume ratio at all rates of air flow, and in all respects equivalent to the vacuum-controlled flow of the two fluids through two separate passages to a common point of mixing.

With this general review as a basis, the search for possible forms and arrangements of parts making up the carburetor proper to operate under the process of proportioning-flow carburetion may be undertaken, and all the available suggestions for the construction of proportionate-flow carburetors collected and compared. This comparative study of the qualitative design of proportioning-flow carburetors must begin with the collection of examples from any source, which must then be grouped into typical classes on the basis of functional or structural similarity, so that class may be compared with class before any attempt is made to analyze differences of detail within each class.

The best source of information for this purpose is clearly the Patent Office record of inventions, and this has accordingly been made the basis of the study which constitutes the bulk of this report. From the official classification list and the definitions of each official class and subclass a selection was made of those that seemed likely to contain patents on carburetors. To assist in this work of discovering the carburetor patents of the United States the services of a competent patent lawyer were enlisted, and under his direction searchers were set to work in the Patent Office, where, aided by its officials, a list of United States carburetor patents was prepared

and copies collected for study and comparison. The detailed steps by which this list was made and copies of each patent secured are given in Part II, with the patent number, date, title, and inventor's name, arranged according to the official classes, subclasses, and cross references.

Having secured copies of these patents, which numbered, after eliminating duplicates, about 3,400, a surprisingly large number in view of the fact that the art is comparatively a new one, every patent was read and reclassification begun as a basis for the comparative study. The first step in this reclassification divided the patents into the two groups of "proportioning-flow carburetors" and "other subjects," the latter including parts, attachments, complete engines, injectors, and all "evaporative carburetors." This made about an equal division and incidentally brought out the interesting fact that practically all the older carburetor patents are evaporative, while practically all the recent ones are proportioning flow as to broad process, the latter beginning about the year 1900 but not becoming really numerous until about the year 1910. This shows that the proportioning-flow carburetor art is about 17 years old, the official life of a patent, and that, therefore, most modern carburetors fall within the patent life and must be either themselves the subject of an active patent or similar in some respects to the disclosures of one or more such patents.

Following this division of United States carburetor patents into "proportioning-flow" cases and "other subjects" the former group was restudied for the purpose of subdivision into classes according to some rational basis of similarity. This step brought out the fact that the present official classification is not a good one, so deficient in elements of distinction as to make necessary the creation of a new classification before any comparative study could be made at all. This new classification has been worked out and the "proportioning-flow" carburetors assigned to places in it in Part III of this report. The very great labor involved in reading, reclassifying, and comparing these thousands of patents in the limited time available has probably led to some errors, which can only be removed by a subsequent checking, but it is believed that the results reported are correct in the main and mistakes are confined to individual cases. To make this sort of study quite complete and of the utmost practical value, not only to designers but also to patent lawyers interested in soliciting new patents or in litigations over existing ones, the new classification and relisting should first be checked and later extended to include the cases of the leading foreign patent offices. It is hoped that the value of so doing will seem to parties interested great enough to have the required funds made available.

Following the reclassification and relisting of the United States proportioning-flow carburetor patents the general characteristics of each new class and subclass is given and structural variations within each class illustrated by photographic reproduction of the drawings of typical patents, the number of which so reproduced is about 450. This illustrated review of the functional and structural characteristics of proportioning-flow carburetors is the subject matter of Part III of this report, which brings out a most amazing wealth of material as to form and arrangement of parts. Even a brief review of this section of the work will convince the most skeptical that so

far as qualitative design of proportioning-flow carburetors is concerned there is little to be desired, and that whatever may be lacking in carburetors or carburetor design is mainly quantitative in character. An effort is made in this comparative study of functional characteristics of the new classes and subclasses to point out the most promising ones from the standpoint of automatic proportioning at any rate of flow, so as to stimulate inventive and designing effort in this direction. Concentration of thought along the more promising lines should result in greater and more rapid advance and perfection of the needed appliances than the scattering of the same effort over the whole field, which includes some types or classes of very much less promise. Of course it is hardly to be expected that there will be a general acceptance of the guides offered, especially among inventors interested in what have been reported as the less promising groups, as the inventive mind normally resists guidance. However this may be, it is hoped that this, the first systematic effort to bring some order into what has been a most chaotic situation, will bear sufficient fruit to justify the serious painstaking labor that has been expended.

No arrangement of parts intended to act as a proportioning-flow carburetor can be conceived that does not involve some mental assumption of a law of flow for the fuel and for the air, relating rate of flow to pressure drop or vacuum. Therefore in every one of these many hundreds of patents there is indirectly involved some such assumption by the inventor, either consciously or unconsciously. With only a few isolated exceptions, not one of them gives any inkling of what flow law is assumed to hold in his device, although nearly all assert their object to be the production of a device that either holds the proportions constant under all conditions or gives some specific sort of control over proportions. In some cases it is quite clear that there is no understanding of the general principles of fluid flow at all, while in others the principles have clearly served to guide the design which, therefore, is at least qualitatively correct and requires only the application of the numerical values in the flow equations to its dimensions to be quantitatively correct also or which can be made correct experimentally without solving the equations numerically. One pretty common violation of the principles of flow for air is neglect of its critical pressure drop limit, according to which no increase of air flow through an orifice takes place after the pressure drop through it exceeds a given value somewhere about four-tenths of the absolute pressure on the supply side. This becomes a most serious interference with proportionality when it is remembered that it does not apply to the liquid orifice acted upon by a similar pressure drop, so that however regularly the air and fuel may increase together as pressure drop increases from zero there comes a time when the air flow ceases to increase while the fuel goes on. Other violations of a general character include the implied assumption of a constant coefficient of efflux for both fuel and air orifices, which may actually vary 100 per cent, also neglect of the differences between capillary and orifice types of fuel passages and the effect of the pressure drop itself on the law of flow for a given passage.

Without undertaking any new experimental determinations of the flow laws and their coefficients for air and gasoline in passages

of the forms and size appropriate to carburetors, it is important that the known principles and facts on the subject be reviewed for two reasons, first to indicate the extent of the justification for the implied assumption of some sort of flow law in all of these inventions, and second to clear the way for such new experimental determinations as may be necessary for undertaking their quantitative design on a natural basis. This review of existing flow laws and flow data forms the subject matter of Part V of this report and proves beyond question that present knowledge is wholly inadequate, and that new experimental determinations must be made just as soon as possible.

Discussion and argument can never be as convincing as proved facts. On the question of proportionality in engine carburetors, no amount of reasoning as to why one of them should or should not be characterized by constant proportions as flow rate changes, can equal in value an experimental determination. For this reason 10 of the leading American carburetors were secured by loan from their makers with the assistance of the Automobile Chamber of Commerce, and were subject to tests for proportionality of air to fuel over a wide range of flow rates. The methods and apparatus used, together with the results obtained, are given in Part VI, the last section of this report. While, as had been expected no one of them was able to keep the proportions constant, as the rate of flow was varied either by throttle position at a constant engine speed or by engine speed at a constant throttle position, yet the actual or possible approach to constancy for the whole group is wonderfully good, considering the absence of exact flow law data and the fact that practically all are products of cut and try or empiric design, as distinguished from the rational or scientific. In some cases the results are so very good as to lead to the belief that substantial constancy within a few per cent of actual constancy of proportions of air to fuel is within reach and will be generally obtainable in carburetors of considerable variety as to form, as soon as flow law data becomes available to designers. Furthermore, should it appear after a series of engine tests on different mixtures that constancy of proportions is not desirable, but that a certain rate of leaning or enriching is desirable as load or speed varies, there is equal promise that it can be obtained. In short, there is every reason to believe that the period of pure invention where wondering, guessing, and assuming constitute the only guides, a period typical of the youth of any new art, is about to give way to the second and permanent stage of designing where proved facts and authentic data form the basis of practice. Such a situation can be most quickly brought about by making the experimental determinations recommended in the "Conclusions," and giving the results the widest possible publicity.

While proportionality control is the prime consideration in any carburetor, it is not in itself sufficient to make a good carburetor, and while proportionality must be controlled through suitable arrangements of properly formed and dimensioned parts based on established flow laws, there are certain other structural elements necessary to a practical carburetor. Finally there is reason to believe that there must be some elements of carburetor design concerned with adaptability to a given engine or to definite operating

conditions of a given engine or to a given fuel that may not be brought out by confining the study to proportions alone, or to steady flow alone, or even to any particular sort of pulsating flow. These are all matters worthy of careful consideration, but somewhat intangible and elusive in character, certainly at the present time. Partly for this reason and partly because all the time available has been consumed in reaching the point here reported, these matters or the items concerned with them can not be given more than a brief notice, which is included so that they be not forgotten or their importance minimized.

Next to proportionality control in basic importance in mixture making comes mixture quality defined by wetness, superheat and pressure, or in general by its physical condition. Other things being equal, mixtures having higher absolute pressures in the intake passages should develop mean effective pressures that are directly proportional to the absolute pressures, and this is a matter of considerable importance in aero engines or others where least weight per horsepower is a prime factor. Some classes of carburetors present fixed areas of air and mixture passages for the flow, while others increase the area as flow rate increases, and therefore should be capable of developing higher mean effective pressures and more power in a given engine unless some other variable or factor neutralizes this possibility. The importance of this mixture pressure factor in mixture density is recognized in some of the patents which disclose fans or blowers driven from the engine and placed either before the carburetor or between it and the engine. This arrangement seems to have some possibilities worth investigating, because the power to pump the charge is far less than the promise of increased engine output, though of course there must be a decrease of thermal efficiency. Adding to such blowers or fans a barometric type of control of delivery pressure would seem to offer a means of neutralizing the effect of altitude on engine power which with aero engines may be considerable.

Such moving parts as fan rotors in the path of the mixture make excellent mixers or mixture homogenizers, and homogeneity of mixture is a matter of coordinate importance with proportionality and density. While with the small passages suited to small engines, a stream of gaseous fuel or of very light gasoline may be relied upon to automatically mix with the air and produce a reasonably homogeneous mixture by the action of the header and valve pocket eddy currents alone. This is not true with heavy gasolines that can only partially vaporize in air at atmospheric temperature, nor is it true with large engines developing several hundred horsepower in a single unit. The heavier the fuel and the larger the intake passage, the more important becomes the matter of specific mixing or homogenizing means involving either fixed or rotating parts. Any unvaporized liquid fuel must be distributed as uniformly as possible through the air in the form of the finest possible fog, and heavy drops or wall streams of liquid must be eliminated if any good effect of proper proportionality control is to be secured.

As an alternative to such stirrers or fine spray fog distributors of unvaporized fuel through the air, the mixture may be heated to remove the liquid, or a light easily vaporizable fuel may be substi-

tuted for the heavy. At the present time, in the absence of exact data on the effects of any liquid in the mixture as to degree, and relying on the established fact that much liquid not specially treated with reference to fog making and air mixing produces very bad combustion, it is recommended that for aero use at least nothing but the lighter gasolines of 76° Baumé or better be used. Some of this grade of gasoline was obtained for the purpose of proportionality tests from the American Oil Works of Titusville, Pa., and its superior vaporization over the common fuel gasoline of the market is proved by the larger drop in temperature observed and reported in the tests as the mixture formed in the carburetor. While such gasoline brings a higher price than the common heavy grade, the excess is not very much considering the superior vaporizing qualities, and such differences in cost as exist are matters of negligible importance for military aero work on this oil-producing country.

The mixture heating alternative to using sufficiently light grades of gasoline for making homogeneous dry mixtures or to spraying means of distributing unvaporized liquid through wet mixtures is one that requires exact experimental tests to determine its comparative value. It is of importance only with heavy fuels carrying constituents that will not vaporize without more heat than can be derived from atmospheric air. While heaters for such mixtures are now available, it is not possible to say whether it is better for a given engine to use wet mixtures with stirrers or fog distributors or to dry them by heat, starting with heavy fuel; or to do neither, but, on the other hand, substitute light fuel. Of course, in the absence of a limit to supply and cost, the last is clearly the wise course. Any heating of the mixture decreases its density just as does a reduction of pressure, so heating must not be resorted to unless the gain from its use exceeds the value of the power lost, and this gain is almost exclusively a gain in thermal efficiency due to better combustion, with a corresponding improvement in lubrication and interior fouling conditions over wet, cold mixtures. No better proof of the situation is available than the two related established facts (*a*) that maximum power and maximum efficiency are not simultaneously obtainable with any but dry mixtures, and (*b*) that the carbon monoxide and the free oxygen in the exhaust can not both be brought to zero at the same time, except with dry mixtures. If therefore heavy fuels must be used, which does not seem to be the case for aero service, it is necessary to experimentally determine the best degree of wetness for both power and efficiency, and the comparative engine performance with dry mixtures made dry by mixture heaters. These are matters of coordinate importance with proportionality for which similar data are required to establish the allowable or required range from constancy if there is any at all for best all-round engine performance. Taken together the results of such tests should lead to the establishment of specification for mixtures best suited for a given engine with the same sort of precision that is now in general use in the steam and vacuum specifications for steam turbines. Given such mixture specifications and the suitable basic scientific data on carburetor phenomena, the carburetor designer may then follow the same general methods used by the designer of steam boilers or condensers.

As to proportionality itself, it must be assumed, pending experimental proof to the contrary, that engines require mixtures in constant proportions because of the chemical nature of the reaction and the thermodynamic requirement that maximum power and efficiency should result from mixtures leaving no unburned fuel and having the highest calorific power per pound of mixture. While among carburetor and engine men there may be found opinions that under this or that condition the mixture must be rich, it is also true that air measurements are practically unknown among them, and therefore the proportions can not be known. Many such cases investigated have led to the conclusion that the meaning intended is rather that the mixture must be made richer than it was or than at other times and not that it must depart from actual constancy.

There are some subsidiary problems of carburetor design worthy of notice, even though time is not available for their investigation at this time. The first group of these includes the several effects of differences in the inertia of air and gasoline, the engine-operating conditions that bring them into action, and the corrective means to be introduced to meet interferences with proper engine working. No matter how many cylinders there may be nor how high the speed, the flow through the passages of a carburetor and through the intake header between it and the inlet valve ports is not a steady but a pulsating flow. There is throughout the mixture making and supply system a series of more or less irregular pressure and velocity waves, and there must be some reflections, returns, and synchronizing heat phenomena. Practically nothing is known of these conditions except that they exist and that should the pulsations vary in amplitude or periodicity bad effects must follow, because in such a case the difference between the inertia of air and gasoline passing through its carburetor feed passages or passing through the manifold passages beyond the carburetor must cause a lag of flow, positive acceleration producing a fuel lag and negative acceleration an air lag. The natural period of oscillation of the fuel in its float chamber and feed passage may synchronize in beats with the mixture pulsations, producing periodic proportionality changes, and the surging speed fluctuations observed in some engines operating on wide-open throttle with a steady lead may be traced to such sources.

Any sudden change of flow rate in the carburetor, whether produced by a quick throttle movement or by a change of lead torque without a throttle movement, must produce mixture proportionality changes by inertia, which, even though momentary, may yet last long enough to seriously interfere with operation or even stop the engine under lead and thereby condemn as unserviceable an otherwise perfectly good carburetor. A sudden increase of flow rate will tend to produce a lean mixture, because the liquid fuel accelerates more slowly than the air, while a sudden decrease of flow rate produces the reverse action, the mixture enriching and in some cases the liquid flow continuing after air flow has stopped enough to visibly spill fuel. Normally such actions as these are most commonly produced by quick movements of the throttle, by means of which the flow rate may be changed in a fraction of a second from practically zero to a very high maximum of several hundred feet per second. Throttle closure is not so serious as throttle opening,

because mixtures momentarily become rich instead of lean and do ignite even when very rich, because also in extreme cases of sudden complete closure the main fuel jet, which is tending to make the mixture overrich, is thrown completely out of action in many modern designs, a low speed or idling jet being brought into action as an alternate. It is on quick throttling opening, suddenly demanding more power, that greatest difficulty arises, because then the mixture naturally tends to become lean by inertia, and, having so low a flame propagative rate, produces back-fires or completely misses fire in extreme cases, the least evil effect being a lag in acceleration of the engine. This has been met by the introduction of the accelerating cup, many forms and connections of which are illustrated in this report, some used in connection with idling jets and others independent. The accelerating cup, so called, is a small chamber, usually shunt connected to the main fuel passage and between the jet and float chamber, so arranged that it fills on slow, steady running and empties through the main or through a separate nozzle whenever the acceleration conditions tend to make the flow through the regular fuel channels insufficient, the fuel from the cup being added to compensate for the momentary main jet leanness. While the accelerating cup is the present solution of leanness due to inertia developed on accelerating the flow and the idling jet is in one sense the equivalent for a decreased flow, the latter also serves another useful function, that of relieving the main passages of the requirement of maintaining proportionality over the lowest ranges of flow rates, and both are comparatively recent developments in this carburetor field, at least so far as adoption and use are concerned.

It is well to point out here that neither the idling jet nor the accelerating cup must be confused with the lifting tube, which is perhaps a still more recent development forced into use by heavy fuels which resist vaporization and which at low flow rates will not rise with the air in the mixing passages, because the air velocity is not great enough to overcome the gravity of the liquid. The lifting tube is a small passage in parallel with the main one, and either a part of it or quite separate, through which the velocity is always great enough to lift the fuel no matter what the flow rate or throttle position, and at high flow rates the lifting tube may remain in action or go out. In any case the fuel passing up the lifting tube has come from the main and not from a separate fuel nozzle, as is the case with the idling passages.

Liquid inertia versus that of air or vapor also plays a part in the mixture-distributing header or intake manifold between the carburetor and the several inlet-valve ports whenever any unvaporized liquid is present. This liquid will not turn at bends in the same proportionate way as does the gaseous constituents, but the walls will act like separators, tending to collect the liquid in streams, which run along the surfaces where the mixture velocity is least. Therefore header design has become a part of the problem of carburetor design since heavy gasolines began to replace the old and once universally used light ones.

Another group of subsidiary design problems is concerned with the supply of liquid to the metering nozzles and involves the fuel passages, the float chamber, float, and float valve, and their design

with reference to tilting or vibration on the one hand and to clogging of small passages with dirt or gum on the other. While all carburetors are not provided with float chambers, some having overflow chambers especially for stationary large tractor use and a few having diaphragm chambers or pressure feeds without any fixed level auxiliary chamber at all, it is nevertheless a fact that practically all carburetors used in transportation work have constant-level chambers, float-valve controlled, from which the metering fuel nozzle takes its supply. Both the designer of the carburetor and the user of the instrument assume that the passages through which the flow is to take place have a definite area and that the level in the float chamber is at a definite distance below the fuel-nozzle tip. Should the fuel passages become clogged with solid matter, due to a failure to properly filter the fuel or clean out a loaded filter member or with gumming matter that is now found occasionally to collect from the fuel itself, it is clear that all calculations and experimental perfection have suddenly been rendered useless. It is not sufficient to assume that these things will not happen, but every carburetor should be so constructed as to make it easy to clean out any of its passages and without requiring the poking of wires into delicately adjusted fine metering orifices, so that their area is changed and the original proportionality destroyed. For the same reason any fuel valves must be so designed that battering or wearing of the seat or valve is either impossible or immaterial so far as proportionality is concerned.

Perhaps as common and serious a mechanical interference with proportionality as any is the variations in float chamber level normally assumed to be constant but just as often not. It is easily possible for the level to change as much or more than the head producing the fuel flow at low flow rates, and if it does there must follow a variation of proportions of a hundred per cent. Fortunately at the normal working flow rates the possible variation in float chamber level is a negligible fraction of the fuel flow head in most carburetors, but in some of them, those in which the vacuum increases least with flow rate, the effect is more serious, and as there are carburetors that produce the most dense mixtures the matter is one of importance. Aside from leaky float valves, or valves of insufficient size, or valves operated with improper linkage to the floats, or having list motion in the linkage, all of which may be responsible for changes of level that should not be permitted, and all of which are easily removable by good mechanical design once they are recognized, there are some operating conditions that cause trouble of a deeper seated kind more difficult to remove. These are tilting and vibration, both of which are apt to be exaggerated to the limit in aero engines. In any but an annular float chamber having the metering nozzle at the center, tilting changes the hydraulic head on the nozzle and when the flow inducing vacuum is small at the nozzle tip, this change of head by tilting may be an appreciable part of the whole flow head and proportionality destroyed. This would seem to be an argument in favor of the annular over the side-connected float chamber and important in proportion as the vacuum at the fuel nozzle is low, though negligible when it is high, but for high capacity light-weight engines the low vacuum has much in its favor as a

means of securing high density mixtures. However, the matter of float chamber form and position may be settled with reference to tilting there remains the vibration interference. Perfectly good carburetors have been observed to overflow their float chambers and spill as much gasoline as they used when vibrating under the shaking influence of the engine at some particular engine speed which seemed to synchronize with the natural period of oscillation of either the float itself or the free liquid in the chamber. No adequate remedy for this seems to be available nor for the overflow and spilling from an excessively tilted chamber, whether concentric or side attached, but it seems clear that this is a mechanical problem worthy of study, the design of constant level chambers that really maintain the level do not spill, in spite of tilting to any angle met in service even abnormally, and quite independent of any vibration.

REPORT No. 11.

PART II.

By CHARLES E. LUCKE.

CARBURETOR PATENTS OF THE UNITED STATES.

As the most fruitful source of information, copies of all patents on carburetors listed in the United States Patent Office have been collected and later reclassified for comparative study. The location of these patents being a difficult matter, in view of the present official classification, the services of a patent attorney, Mr. A. L. Kent, of New York City, were enlisted, and under his direction the search was conducted, lists for the various subclasses prepared, and copies of each one, after eliminating duplicates, secured.

As a first step the following definition of what was wanted was submitted to Mr. Kent as a guide in his work:

For the purpose of this inquiry a carburetor may be defined as an appliance to be attached to an internal-combustion engine, adapted to receive air and liquid fuel, and to deliver to the engine an explosive mixture.

By this definition all appliances that are not distinctly attachments are excluded, but there is included everything that makes an explosive mixture from liquid fuel and air when attached to the suction or intake port of an internal-combustion engine. More particularly are we concerned, though by no means exclusively, with that group of carburetor appliances in which the suction of the engine through some passage produces a reduction of pressure at a given point and induces a flow of gasoline by reason of that reduced pressure. This class is often described as the jet carburetor, vacuum jet, suction spray, etc. This is the class in common use on present automobiles, motor boats, aeroplanes, tractors, railroad gasoline cars and locomotives, and a considerable number of gasoline stationary engines.

The foregoing was later supplemented by more specific instructions to disregard internal vaporizing devices; that is, those in which the fuel is vaporized in the engine cylinder or in a combustion chamber, including devices in which the fuel liquid is sprayed into the cylinder without being previously mixed with air, and devices in which a pump supplies the fuel liquid unmixed with air to the cylinder or other combusion chamber; and to list devices in which the fuel liquid enters the cylinder or combustion chamber as a vapor, including those in which the liquid is externally vaporized but internally mixed with a part or all of the air, devices in which a pump supplies the liquid to a charge-forming device, and carburetors and parts and attachments for operating with kerosene and other comparatively heavy oils.

With this information, the procedure followed is given by Mr. Kent, as follows:

I first went over with you the definition of subclasses in the two classes of the Patent Office Classification of Patents which at the time contained most of the carburetor patents; that is, class 48, gas, heating, and illuminating; and

class 123, internal-combustion engines; and the following subclasses were selected to be ordered complete, namely:

In class 48: Subclasses 144, 145, 146, 148, 149, 150, 150.1, 150.2, 150.3, 151, 152, 153, 154, 154.1, 155, 155.1, 155.2, 156, 157, 158, 159, 160, 163, 164, 165, 166, 167, 168, 169, and 219.

In class 123: Subclasses 119, 121, 131, and 132.

In order to be sure of getting all the patents in these subclasses, and also copies of patents cross-referenced into these subclasses from other subclasses, I had copies made of the subclass lists in the Publications Division of the Patent Office and then had these lists checked and completed from the bundles of patents in the Patent Office search room; and for each subclass I had the cross-reference patents in the bundles in the search room listed and then had these cross-reference patent lists checked and completed from cross-reference lists in the Classification Division of the Patent Office. The patents in the above subclasses were then ordered from these lists, excepting the cross-reference patents, and a single list of cross-reference patents from the several subclasses was made up, eliminating duplicates, and the patents on such list were also ordered.

These patents, about 3,500 in all, including several hundred of the cross-reference patents which were duplicates of patents belonging to the subclasses and which are omitted from list No. 2 above referred to, were, through the courtesy of the Commissioner of Patents, furnished by the Patent Office without charge after the purpose for which they were wanted by you was explained to the commissioner, and with the understanding that they were to be obtained only for such use.

I also had the following subclasses in class 123 and various other classes searched or examined for the purpose of selecting carburetor patents such as you were interested in:

Class 60: Subclasses 4, 28, 36, and 37 (searched).
Class 67: Various subclasses (examined).
Class 103: Subclasses 67, 78, 79, and 84 (searched).
Class 115: Subclass 13 (searched).
Class 122: Subclass 24 (searched).
Class 123: Subclasses 3, 4, 7 to 18, 20, 21, 22, 25 to 29, 34 to 59, 62 to 69, 71, 73, 75, 76, 78, 79, 82, 92, 97 to 106, 108, 110 to 118, 122 to 130, 133 to 142, 180, and 191 (all except a few searched, and a number of other subclasses looked into).
Class 126: Subclasses 249 and 251 (searched).
Class 158: Subclasses 36 to 73 (searched).
Class 160: All three subclasses (examined).
Class 162: All three subclasses (examined).
Class 230: Subclass 13 (searched).
Class 236: All subclasses (examined).
Class 257: Subclass 52 (searched).
Class 261: All subclasses (searched).

Most of the above subclasses were searched through, each patent being looked at. Some subclasses were only examined, or looked into, sufficiently to decide that they contained no patents of interest. In class 123, patents listed from subclass 29, oil engines, pump supply to air inlet, two cycle, were not ordered or included in lists furnished to you, as they were similar in the carburetors shown to patents ordered from subclass 28, oil engines, pump supply to air inlet, four cycle, which I understood from you were not of interest to you.

Searching the above subclasses resulted in the listing of some 2,500 patents, substantially all from classes 123 and 261. From these lists patents contained in the lists of subclasses ordered complete and their cross-reference patents were stricken off and only those remaining were ordered and listed in the lists which I am furnishing you of the searched subclasses.

As I have already explained to you, class 261, gas and liquid contact apparatus, is a new class which, although established some time ago with three or four subclasses, has just recently anad since the patents in subclasses ordered for you complete were obtained, been revised and expanded to include, in 126 subclasses, carburetors and other gas and liquid contact apparatus selected from various classes in which such apparatus might be found. The official definition of this class is:

"Apparatus especially adapted to produce an intimate contact between gases and liquids to exchange properties or mutually modify conditions.

"NOTE.—This class includes devices generally known as air and gas washers, air moisteners, carburetors, carbonators, jet condensers, coolers, heaters, and the like, operating by direct contact of the two fluids."

he time the new subclasses in this class were established, a number of
sses in other classes were abolished, including the following subclasses
s 48, which were listed and ordered for you as above explained, viz, sub- 145, 146, 148, 149, 150, 150.1, 150.2, 150.3, 151, 152, 153, 154, 154.1, 155, 155.2, 156, 157, 158, 159, 163, 164, 165, 166, 167, 168, and 169. Many of
ents from these abolished subclasses of class 48 were transferred to the
established subclasses of class 261. In searching the subclasses of class
large number of the patents in the subclasses of class 48 ordered com-
ere found and listed, but have been omitted from the list furnished you
nts found in this class to avoid duplication, as above explained.
nk that you have received a fairly complete set of carburetor patents of
d in which you were interested, but further examination and search
undoubtedly result in adding a more or less considerable number of
, although the Patent Office system of cross-referencing patents from
bclass to another makes it quite possible that the number of patents
may be comparatively small.

h patents in these lists as were found after examination to be
rtioning carburetor cases have been marked with an asterisk
These cases have been reclassified in accordance with the defi-
of the succeeding sections of this report, Part III, and they
h material to illustrate the discussion of the characteristics
h of the new classes and subclasses, as reported in Part IV of
eport.

lists of carburetor patents here reported include:

: No. 1.—Patents in the subclasses ordered complete, arranged
ling to classes and subclasses, and giving number, date, inven-
name, and title of each patent belonging in each of the several
sses, and the numbers only of patents assigned as cross-ref-
patents to each subclass.

: No. 2.—Cross-reference patents from list No. 1, with patents
ging in, or regularly assigned to, the subclasses of list No. 1
ed.

: No. 3.—Selected patents from searched subclasses arranged
ling to class and subclass, with patents which appear in the
ous lists omitted.

: No. 4.—Selected cross-reference patents from the searched
sses, with patents which appear in either of the three previous
mitted.

List of subclasses of the United States Patent Office Classifi-
of Patents which were ordered complete or searched for car-
r patents, giving the official class and subclass numbers and
of subclasses ordered complete, and class numbers and titles
ubclass numbers of subclasses searched:

1. Subclasses ordered complete.
2. Subclasses searched or examined.

Lists of United States patents obtained and examined:

: No. 1.—Patents in the subclasses ordered complete, arranged
ling to classes and subclasses, and giving number, date, in-
r's name, and title of each patent belonging in each of the
l subclasses, and the numbers only of patents assigned as cross-
nce patents to each subclass.

: No. 2.—Cross-reference patents from list No. 1, with patents
ging in, or regularly assigned to, the subclasses of list No. 1
ed.

t No. 3.—Selected patents from searched subclasses arranged
ling to class and subclass, with patents which appear in the
ous lists omitted.

List No. 4.—Selected cross-reference patents from the searched subclasses, with patents which appear in either of the three previous lists omitted.

A. List of Subclasses of the United States Patent Office Classification of Patents which were Ordered Complete or Searched for Carburetor Patents, giving the Official Class and Subclass Numbers and Titles of Subclasses ordered complete, and Class Numbers and Titles and Subclass Numbers of Subclasses searched.

1. *Subclasses ordered complete:*
   Class 48, gas, heating and illuminating—
      Subclass 144, carburetors.
      Subclass 145, carburetors, regulating.
      Subclass 146, carburetors, series.
      Subclass 148, carburetors, heater.
      Subclass 149, carburetors, heater, air.
      Subclass 150, carburetors, oil-feed.
      Subclass 150.1, carburetors, oil-feed, multiple-supply.
      Subclass 150.2, carburetors, oil-feed, multiple-jet.
      Subclass 150.3, carburetors, oil-feed, multiple-jet, progressive.
      Subclass 151, carburetors, oil-feed, float-valves.
      Subclass 152, carburetors, oil-feed, pump.
      Subclass 153, carburetors, oil-feed, rotary.
      Subclass 154, carburetors, oil-feed, spray.
      Subclass 154.1, carburetors, oil-feed, suction-controlled valve.
      Subclass 155, carburetors, atomizers.
      Subclass 155.1, carburetors, atomizers, constant-level.
      Subclass 155.2, carburetors, atomizers, constant-level, automatic-dilution.
      Subclass 156, carburetors, capillary.
      Subclass 157, carburetors, capillary, spiral-passage.
      Subclass 158, carburetors, capillary, vertical-screen.
      Subclass 159, carburetors, capillary, zigzag-passage.
      Subclass 160, carburetors, gravity.
      Subclass 163, carburetors, osmotic.
      Subclass 164, carburetors, pivoted.
      Subclass 165, carburetors, pivoted, revolving.
      Subclass 166, carburetors, submerged-blast.
      Subclass 167, carburetors, submerged-blast, coil.
      Subclass 168, carburetors, surface.
      Subclass 169, carburetors, surface, float.
      Subclass 219, processes, carbureting.
   Class 123, internal-combustion engines—
      Subclass 119, charge-forming devices.
      Subclass 121, charge-forming devices, combined oil and gas.
      Subclass 131, charge-forming devices, atomizers.
      Subclass 132, charge-forming devices, atomizers, constant-level.
2. *Subclasses searched or examined:*
   Class 60, miscellaneous heat-engine plants—
      Subclasses 4, 28, 36, and 37 (searched).
   Class 67, illuminating burners.
      Various subclasses examined.
   Class 103, pumps—
      Subclasses 67, 78, 79, and 84 (searched).
   Class 115, marine propulsion—
      Subclass 13 (searched).
   Class 122, liquid heaters and vaporizers—
      Subclass 24 (searched).
   Class 123, internal-combustion engines—
      Subclasses 3, 4, 7 to 18, 20, 21, 22, 25 to 29, 34 to 59, 62 to 69, 71, 73, 75, 76, 78, 79, 82, 92, 97 to 106, 108, 110 to 118, 122 to 130, 133 to 142, 180, and 191 (all except a few searched)—

2. *Subclasses searched or examined*—Continued.
   Class 126, stoves and furnaces—
      Subclasses 249 and 251 (searched).
   Class 158, liquid and gasoeous fuel burners—
      Subclasses 36 and 73 (searched).
   Class 160, steam and vacuum pumps—
      All three subclasses examined.
   Class 162, injectors and ejectors—
      All three subclasses examined.
   Class 230, air and gas pumps—
      Subclass 13 (searched).
   Class 236, dampers, automatic—
      All subclasses examined.
   Class 257, heat exchange—
      Subclass 52 (searched).
   Class 261, gas and liquid contact apparatus—
   All subclasses searched.

B. Lists of United States Patents Obtained and Examined.

LIST No. 1.

Patents in the Subclasses Ordered Complete, Arranged According to Classes and Subclasses, and Giving Number, Date, Inventor's Name, and Title of Each Patent Belonging in Each of the Several Subclasses, and the Numbers Only of Patents Assigned as Cross-Reference Patents to Each Subclass.

CLASS 123, INTERNAL-COMBUSTION ENGINES.

SUBCLASS 119, CHARGE-FORMING DEVICES.

302,478. July 22, 1884. Gaume. Gas engine.
306,925. Oct. 21, 1884. Hopkins. Gas engine.
345,596. July 13, 1886. Lenoir. Gas engine.
367,937. Aug. 9, 1887. Shaw. Combined gas and oil engine.
407,998. July 30, 1889. Debouttevllle & Malandin. Apparatus for carbureting air.
430,235. June 17, 1890. Ritchey. Preparation of gas for gas engines.
517,077. Mar. 27, 1894. Thayer. Gas engine.
566,263. Aug. 18, 1896. Wolf. Gas or petroleum engine or motor.
632,509. Sept. 5, 1899. Ayres. Carbureting device for gas or explosive engines.
638,655. Dec. 5, 1899. Taylor. Coupling gas motors and gas producers.
644,922. Mar. 6, 1900. Johnson & Gillooly. Carbureter.
657,662. Sept. 11, 1900. La Roche. Controlling means for explosive engines.
663,549. Dec. 11, 1900. Mathieu. Carburetor.
673,123. Apr. 30, 1901. Henderson. Carburetor.
*680,115. Aug. 6, 1901. Blomstrom. Vaporizer for internal-combustion engines.
*688,349. Dec. 10, 1901. Scott & Bonney. Vaporizing device for explosive engines.
696,909. Apr. 1, 1902. McCormick & Miller. Carbureting device for explosive engines.
784,699. Mar. 14, 1905. Pederson & Anderson. Feed valve for gasoline engines.
789,321. May 9, 1905. Gerdes. Means for regulating the air feed to gas motors.
*806,434. Dec. 5, 1905. Schebler. Carburetor for hydrocarbon motors.
*806,822. Dec. 12, 1905. Millard. Carburetor.
868,834. Oct. 22, 1907. Bassford. Explosive engine.
881,803. Mar. 10, 1908. Jaubert. Propulsion of submarine boats.
*897,259. Aug. 25, 1908. Winton & Anderson. Method of carbureting air for explosive engines.
924,926. June 15, 1909. Parker. Muffler for mixers.
930,596. Aug. 10, 1909. Hanks. Carburetor jacket or casing.

971,971. Oct. 4, 1910. Cassedy & Purset. Charge-forming device for internal-combustion engines.
973,118. Oct. 18, 1910. Stockton. Gas engine.
1,006,809. Oct. 24, 1911. Ulrich & Rahr. Carburetor for internal-combustion engines.
1,018,447. Feb. 27, 1912. Schenck. Valve mechanism.
1,021,079. Mar. 26, 1912. Stewart. Mixing attachment for carburetors.
1,022,027. Apr. 2, 1912. Hyde & Gage. Hydrocarbon engine.
1,037,953. Sept. 10, 1912. Michener. Internal-combustion engine.
1,051,690. Jan. 28, 1913. Colwell. Internal-combustion engine.
1,075,051. Sept. 9, 1913. Kendall. Controlling device for internal-combustion engines.
1,096,901. May 19, 1914. Freschal & Freschal. Motor fuel-supplying apparatus.
1,098,164. May 26, 1914. Mooney. Auxiliary gas generator for engines.
1,105,592. July 28, 1914. Bassford. Explosive engine.
*1,105,687. Aug. 4, 1914. Ottawa. Carburetor.
*1,112,257. Sept. 29, 1914. Brush. Mixture-supplying apparatus for internal-combustion engines.
1,121,137. Dec. 15, 1914. Schoonmaker. Internal-combustion engine.
1,123,114. Dec. 29, 1914. Diehl. Means for moistening the air used in explosion engines.
1,128,830. Feb. 16, 1915. Wharton. Economizer for internal-combustion engines.
1,138,581. May 4, 1915. Shumaker. Charge-forming device for internal-combustion engines.
1,150,562. Aug. 17, 1915. Vose. Electrically-controlled vaporizer for internal-combustion engines.
1,152,080. Aug. 31, 1915. Denney & Osborn. Air-supplying attachment for carburetors.
1,170,788. Feb. 8, 1916. Walch. Mixing device.

Cross reference patents, class 123, subclass 119.

240,994	497,046	602,820	673,138	855,191	965,632	1,120,828
275,238	505,767	623,190	692,071	857,980	1,013,955	1,158,179
286,030	552,312	623,361	745,055	868,281	1,030,388	
370,258	563,548	627,359	747,190	883,240	1,038,300	
376,638	564,155	632,888	775,859	895,222	1,054,205	
385,121	564,769	633,014	790,325	913,121	1,066,391	
421,474	592,794	657,140	806,125	926,756	1,099,445	
450,091	593,034	660,482	812,860	946,737	1,109,192	

SUBCLASS 121, CHARGE FORMING DEVICES, COMBINED OIL AND GAS.

*574,183. Dec. 29, 1896. Underwood. Mixer for gas engines.
*658,594. Sept. 25, 1900. Shartle & Miller. Gas engine.
*679,053. July 23, 1901. Johnston. Vaporizer for explosive engines.
*792,894. June 20, 1905. Green. Oil or gasoline attachment for gas engines.
974,255. Nov. 1, 1910. Galusha. Power plant.
1,112,188. Sept. 29, 1914. Atwood. Compound induction valve for internal-combustion engines.

Cross-reference patents, class 123, subclass 121.

550,675	555,373	585.115	613,757	645,044	753,510	1,021,079
403,367	555,717	587,627	632,859	679,380	909,558	

SUBCLASS 131, CHARGE FORM DEVICES, ATOMIZERS.

*695,060. Mar. 11, 1902. Krastin. Vaporizer for hydrocarbon engines.
855,191. May 28, 1907. Low. Hydrocarbon motor.
*856,638. June 11, 1907. Higgins, jr., Carburetor.
857,566. June 18, 1907. Franchetti. Atomizing spray nozzle.
*858,586. July 2, 1907. Duryea. Means for supplying explosive vapors for operating rock drills.

883,981. Apr. 7, 1908. Shanck. Gas generator for explosive engines.
886,518. May 5, 1908. Johnston. Fuel spray for internal-combustion motors.
924,044. June 8, 1909. Durr. Apparatus for injecting fuel into internal-combustion motors.
960,057. May 31, 1910. Turnbull, jr. Means for feeding fluid fuel.
*1,003,019. Sept. 12, 1911. Webb. Gas engine.
1,027,054. May 21, 1912. Leflaive. Atomizer for fluid-fuel motors.
1,028,713. June 4, 1912. Grinewezki. Carbureter for internal-combustion motors.
1,069,341. Aug. 5, 1913. Lemp. Pulverizer for oil engines.
1,094,075. Apr. 21, 1914. Kiser. Fuel atomizer.
1,112,877. Oct. 6, 1914. Wigelius. Fuel injector.
1,112,878. Oct. 6, 1914. Wigelius. Fuel injector.
1,117,845. Nov. 17, 1914. Hesselman. Vaporizer for internal-combustion engines.
1,122,770. Dec. 29, 1914. Lake. Fuel injector for internal-combustion engines.
1,130,229. Mar. 2, 1915. Wigelius. Fuel sprayer.
1,135,418. Apr. 13, 1915. Wigelius. Gas motors.
1,142,623. June 8, 1915. Regenbogen. Fuel injector.
1,149,322. Aug. 10, 1915. Baker. Method of and apparatus for feeding liquid fuel to internal-combustion engines.
1,155,266. Sept. 28, 1915. Pasel. Fuel-injecting device.
1,157,273. Oct. 19, 1915. Windeler. Fuel injector.
1,157,305. Oct. 19, 1915. Frost. Pulverizer for oil engines.
1,157,315. Oct. 19, 1915. Lemp. Fuel injector.
1,163,059. Dec. 7, 1915. Bell. Carbureting device.
1,164,064. Dec. 14, 1915. Brown. Fuel injector.
1,171,787. Feb. 15, 1916. Harris. Atomizer for internal-combustion engines.
1,184,779. May 30, 1916. Shaw. Aerating fuel pump for explosive motors.
1,182,120. May 9, 1916. Verhey. Internal-combustion engine.
1,189,338. July 4, 1916. Askew. Internal-combustion engine.

Cross-reference patents, class 123, subclass 131.

153,952	500,477	609,831	745,573	876,287	930,483	1,096,585
225,778	504,723	612,258	765,880	904,455	943,684	1,099,995
228,547	507,989	617,530	800,996	904,508	948,977	1,101,271
238,757	542,410	637,299	807,835	904,855	966,581	1,121,137
302,045	552,718	659,911	816,549	908,112	982,825	1,142,440
309,835	562,307	690,486	863,516	918,607	989,026	1,143,258
350,200	574,614	703,769	867,605	922,145	1,021,079	1,150,562
350,769	582,073	706,494	872,419	922,383	1,060,053	1,161,095
386,029	583,982	730,084	873,392	924,926	1,083,111	

SUBCLASS 132, CHARGE FORMING DEVICES, ATOMIZERS, CONSTANT LEVEL.

* 595,552. Dec. 14, 1897. Banki & Csonka. Gasoline motor.
* 623,568. Apr. 25, 1899. Secor. Explosive engine.
* 633,274. Sept. 19, 1899. Riotte. Vaporizer for gas engines.
* 657,739. Sept. 11, 1900. Kiltz. Vaporizer for petroleum engines.
* 658,267. Sept. 18, 1900. Kennedy. Gasoline engine fuel-oil feeder.
* 671,743. Apr. 9, 1901. White. Mixing and vaporizing device for explosive engines.
678,077. July 9, 1901. Webb. Fuel-supply controller for hydrocarbon engines.
* 681,382. Aug. 27, 1901. Westman. Feed cup for explosive engines.
* 711,902. Oct. 21, 1902. Leppo. Carburetor for explosive engines.
765,880. July 26, 1904. Chamberlin. Means for feeding the induction ports or fuel inlets of internal-combustion engines.
* 790,379. May 23, 1905. Mingst. Carburetor for hydrocarbon engines.
* 801,539. Oct. 10, 1905. Moreland. Carburetting apparatus and feed therefor for internal-combustion engines.
* 805,979. Nov. 28, 1905. Menges. Carburetor.
* 817,941. Apr. 17, 1906. Stute. Carburetor.
842,261. Jan. 29, 1907. Smith. Means for controlling the supply of vapor to internal-combustion engines.

* 887,370. May 12, 1908. Winton & Anderson. Carburetor.
* 896,559. Aug. 18, 1908. Longuemare. Air-inlet regulator for carburetors.
* 898,920. Sept. 15, 1908. Pierson. Carburetor.
903,479. Nov. 10, 1908. Kemp. Safety carbureting plant.
* 906,980. Dec. 15, 1908. Winton & Anderson. Carburetor.
933,888. Sept. 14, 1909. Charter. Float-controlled oil-supply device for gas engines.
1,047,595. Dec. 17, 1912. Twigg. Speed-regulating carburetor.
1,072,402. Sept. 2, 1913. Peregrine. Gas generator for explosive engines.
* 1,106,802. Aug. 11, 1914. Goldberg. Carburetor.
1,166,560. Jan. 4, 1916. Tice. Carburetor.

Cross-reference patents, class 123, subclass 132.

477,295	664,200	747,264	823,742	855,582	931,389	1,117,641
542,043	677,283	771,492	832,183	865,522	948,612	1,117,642
549,939	686,092	791,501	832,532	872,336	952,326	
554,699	686,101	796,712	839,707	886,527	958,897	
557,496	690,610	806,434	844,900	897,259	961,152	
605,815	696,146	806,460	846,471	907,953	975,796	
622,891	733,625	810,435	849,538	920,231	1,025,814	
627,857	740,571	822,172	851,759	928,939	1,063,866	

CLASS 48, GAS, HEATING AND ILLUMINATION.

SUBCLASS 144, CARBURETORS.

49,526. Aug. 22, 1865. Irwin. Improved apparatus for carbureting air.
55,949. June 26, 1866. ———. Improved apparatus for carbureting air.
80,918. Aug. 11, 1868. Coons. Improved carburetor.
94,360. Aug. 31, 1869. Tirrill. Carburetor.
103,836. June 7, 1870. Boyle. Improvement in pneumatic gas machines.
105,561. July 19, 1870. Foster & Ganster. Improvement in gas apparatus for railroads, etc.
107,263. Sept. 13, 1870. Hyde. Improvement in blowpipes.
115,798. June 6, 1871. Whitney. Improvement in apparatus for carbureting gas and air.
130,004. July 30, 1872. Averell. Improvement in carburetors.
134,240. Dec. 24, 1872. Averell. Improvement in carburetors.
137,307. Apr. 1, 1873. Kromschroeder. Improvement in carburetors.
151,896. June 9, 1874. McFaddin. Improvement in apparatus for carbureting air and gas.
153,872. Aug. 4, 1874. Wheeler. Improvement in carbureting apparatus.
169,658. Nov. 9, 1875. Randolph. Improvement in apparatus for lighting railway cars.
181,544. Aug. 29, 1876. Tirrill. Improvement in carburetors.
257,247. May 2, 1882. Shaler. Carburetor.
268,878. Dec. 12, 1882. Tessie du Motay & Ster. Process and apparatus for distributing liquid fuel in cities.
342,445. May 25, 1886. Lawrence. Carburetors.
478,549. July 12, 1892. Bailey. Fuel-gas apparatus.
494,442. Mar. 28, 1893. Ruthven. Carbureting apparatus.
527,789. Oct. 23, 1894. Heckert & Rowland. Process and apparatus for making gas.
560,388. May 19, 1896. Barker. Apparatus for carbureting air.
650,367. May 29, 1900. Bouchaud-Praceiq. Apparatus for carbureting air and transporting liquids.
687,756. Dec. 3, 1901. Kemp. Carburetor.
693,273. Feb. 11, 1902. Jervis. Carburetor.
716,452. Dec. 23, 1902. Mainwaring. Carburetor.
760,296. May 17, 1904. Anderson & Erickson. Gasoline gas-making machine.
818,397. Apr. 17, 1906. Tresenreuter. Carburetor.
895,717. Aug. 11, 1908. Boltenstern. Gas machine.
908,402. Dec. 29, 1908. Fox. High-pressure lighting and heating apparatus.
923,377. June 1, 1909. Schmidt. Carburetor.
933,064. Sept. 7, 1909. Dennie. Carbureted-air apparatus.
940,916. Nov. 23, 1909. Alldredge. Supply tank and carburetor for gas plants.

*1,008,155. Nov. 7, 1911. Iber. Attachment for internal-combustion engines.
1,023,397. Apr. 16, 1912. Rogers. Attachment for carburetors.
1,076,401. Oct. 21, 1913. Armstrong. Gas generator.
*1,098,783. June 2, 1914. Daimler. Carburetor.
*1,105,003. July 28, 1914. Secor. Carburetor.
*1,123,876. Jan. 5, 1915. Hiddleson. Carburetor.
1,152,298. Ag. 31, 1915. Cornelius. Charge-forming device.
1,161,243. Nov. 23, 1915. Oliver. Gravity valve.
*1,179,664. Apr. 18, 1916. Shakespeare & Schmidt. Carburetors.
9,037 Re. Jan. 6, 1880. Randolph. Apparatus for lighting railway cars.

Cross-reference patents, class 48, subclass 144.

156,172	284,373	554,207	951,590	1,024,501	1,082,865	1,111,620
168,910	489,762	932,478	995,882	1,043,691		

SUBCLASS 145, CARBURETORS, REGULATING.

24,199. May 31, 1859. Covel. Carburetors.
27,190. Feb. 14, 1860. Laubach. Vapor burner.
34,557. Mar. 4, 1862. Bassett. Carburetor.
38,357. Apr. 28, 1863. Gwynn. Carburetor.
42,469. Apr. 26, 1864. Griffin. Improved apparatus for vaporizing hydrocarbon liquids for illuminating.
64,776. May 14, 1867. Laubach. Improved apparatus for carbureting gas.
65,705. June 11, 1867. Stevens. Improved apparatus for treating air and hydrocarbon vapor for illuminating gas.
66,067. June 25, 1867. Bassett. Apparatus for carbureting and regulating the flow of gas.
66,545. July 9, 1867. Wood. Apparatus for carbureting air and regulating its flow.
67,216. July 30, 1867. Ransom. Carbureting apparatus.
67,576. Aug. 6, 1867. Pease. Improved apparatus for carbureting air.
67,840. Aug. 20, 1867. Beacher. Improved valve for gas generators.
71,514. Nov. 26, 1867. MacDougall. Portable gas apparatus and carburetor.
72,825. Dec. 31, 1867. Earseman & Gray. Carbureting coal gas.
83,147. Oct. 20, 1868. Frank. Improved machine for carbureting air.
103,994. June 7, 1870. Dailey. Carburetor.
104,042. ———.
115,182. May 23, 1871. Edmonds. Improvement in apparatus for carbureting.
125,194. Apr. 2, 1872. Holton. Improvement in carburetors.
141,886. Aug. 19, 1873. Olney. Gas apparatus for railway cars.
149,111. Mar. 1, 1874. Fish. Apparatus for carbureting gas and air.
150,827. May 12, 1874. Cayce. Improvement in carburetors.
153,538. July 28, 1874. Cohen. Carbureting gas machine.
164,825. June 22, 1875. Fish. Apparatus for carbureting and purifying gas and air.
170,097. Nov. 16, 1875. McKissock. Improvement in carburetors.
170,788. Dec. 7, 1875. Vasquez. Improvement in gas-generating apparatus.
204,974. June 18, 1878. Hyams. Apparatus for carbureting air.
224,576. Feb. 17, 1880. Boeklen. Illumination of railroad cars.
226,122. Mar. 30, 1880. Smyers. Carbureting apparatus.
238,818. Mar. 15, 1881. Walmsley. Carburetor.
311,858. Feb. 3, 1885. Strong. Gas machine.
353,499. Nov. 30, 1886. Plass. Apparatus for lighting and heating railway cars, etc.
385,485. July 3, 1888. Stubbers. Carburetor.
554,630. Feb. 11, 1896. Vestal & Ray. Gas generator.
563,799. July 14, 1896. Porter. Carburetor.
596,658. Jan. 4, 1898. Feil. Apparatus for producing uniform mixtures of air and inflammable vapor.
622,489. Apr. 4, 1899. Kelly. Carburetor.
623,321. Apr. 18, 1899. Lara. Carburetor.
639,965. Dec. 26, 1899. Doze. Carburetor.
673,542. May 7, 1901. Johnson. Apparatus for making gas.
759,539. May 10, 1904. Merrege. Carburetor.

763,965. July 5, 1904. Colbath. Carburetor.
767,485. Aug. 16, 1904. Merrege. Carburetor.
768,732. Aug. 30, 1904. Bruce. Carburetor.
793,776. July 4, 1905. Fallin. Carburetor.
828,284. Aug. 7, 1906. Glasscoe. Carburetor.
841,779. Jan. 22, 1907. Hinman & Wellman. Gas apparatus.
842,846. Jan. 29, 1907. Carburetor air apparatus.
843,554. Feb. 5, 1907. Schrader. Carburetor.
848,963. Apr. 2, 1907. Busenbenz. Gas-manufacturing apparatus.
852,685. May 7, 1907. Speer. Carbureting apparatus.
854,604. May 21, 1907. Reichenbach. Carburetor.
860,334. July 16, 1907. Schell. Carburetor.
883,171. Mar. 31, 1908. Colbath. Carburetor.
941,393. Nov. 30, 1909. Warmsley. Carburetor.
944,482. Dec. 28, 1909. Elliott. Carburetor.
947,639. Jan. 25, 1910. Hill & Westwood. Carburetor.
947,717. Jan. 25, 1910. Mieville. Apparatus for the production of carbureted air.
949,140. Feb. 15, 1910. Becker. Automatic carbureting machine.
953,606. Mar. 29, 1910. Grandjean. Carbureting apparatus.
959,350. May 24, 1910. Johnson. Carbureting apparatus.
959,745. May 31, 1910. Hulse. Regulator for gas-lighting systems.
976,781. Nov. 22, 1910. Busch. Apparatus for producing carbureted air.
1,022,451. Apr. 9, 1912. Whitacre. Carburetor.
1,024,501(?). Apr. 30, 1912. Dixón. Lighting apparatus.
1,064,273. June 10, 1913. Wortman. Carbureting apparatus.
1,080,471. Dec. 2, 1913. Olsen. Air-gas apparatus.
1,082,070. Dec. 23, 1913. Cox. Air-gas apparatus.
1,089,471. Mar. 10, 1914. Hunt & Peloubet. Carbuetor.
1,109,085. Sept. 1, 1914. Schmidt. Carbureting apparatus.
1,116,325. Nov. 3, 1914. Ponarouse. Carburetor.
Re. 2357. Sept. 18, 1866. Bassett.
Re. 5465. ———.

Cross-reference patents, class 48, subclass 145.

35,144	57,940	97,748	440,486	672,507	951,590	1,027,456
43,264	59,991	102,784	500,772	688,408	962,860	1,050.322
49,934	68,666	103,036	531,780	725,148	975,038	1,070,394
50,076	81,232	151,392	596,321	760,296	976,885	1,108,081
50,987.	82,244	221,680	607,888	813,796	979,761	
52,876	82,786	224,592	607,889	839,540	982,490	
53,504	84,332	262,991	618,108	855,094	1,017,572	
57,164	84,941	395,616	658,020	950,825	1,027,340	

SUBCLASS 146, CARBURETORS, SERIES.

47,258. Apr. 11, 1865. Simmons & Irwin. Improved apparatus for carbureting air.
54,132. Apr. 24, 1866. Drake. Improvement in apparatus for carbureting air.
82,359. Sept. 22, 1868. Slatter. Improved carburetor.
92,317. July 6, 1869. Kelley. Improved gas generator.
112,111. Feb. 28, 1871. Bell. Improvement in apparatus for carbureting air.
113,317. Apr. 4, 1871. Lutewitte. Improvement in apparatus for carbureting air and gas.
120,590. Nov. 7, 1871. Lowden. Improvement in portable gas apparatus.
193,407. July 24, 1877. Hill. Apparatus for manufacturing illuminating gas.
211,194. Jan. 7, 1879. Tackeberry. Apparatus for carbureting air.
221,942. Nov. 25, 1879. Savage. Improvement in vapor-gas apparatus.
307,132. Oct. 28, 1884. Mayer. Apparatus for manufacturing gas.
324,177. Aug. 11, 1885. Singer. Carburetor.
356,477. Jan. 25, 1887. Johnston. Process and apparatus for manufacturing heating gas.
370,936. Oct. 4, 1887. Drake. Carbureting apparatus.
405,747. June 25, 1889. Snyder & Stephenson. Apparatus for carbureting air or gas.
457,803. Aug. 18, 1891. Vanorman. Carburetor.

l. Oct. 18, 1892. Parris. Carbureting apparatus.
3. July 18, 1893. Fontaine. Apparatus for carbureting air.
2. Apr. 24, 1894. Bidelman. Apparatus for the manufacture of gas.
3. July 31, 1900. Steele. Carburetor.
3. Oct. 9, 1900. Hodder. Carburetor.
5. Apr. 30, 1901. Hopkins. Carburetor.
2. May 31, 1901. McCormick. Carburetor.
l. Jan. 7, 1902. Van Der Made. Apparatus for carbureting air.
5. Feb. 4, 1902. Doolan. Carburetor.
7. June 17, 1902. Deringer. Carburetor.
7. Aug. 26, 1902. Betzel. Carburetor.
7. Nov. 18, 1902. Steele. Gas-making apparatus.
7. Dec. 16, 1902. Harvey. Carburetor.
l. July 28, 1903. Avery & Smith. Apparatus for carbureting air.
5. Nov. 8, 1904. Marshall. Apparatus for carbureting air.
5. Nov. 27, 1906. Wright. Carburetor.
5. Feb. 17, 1907. Colbath. Carburetor.
33. Jan. 9, 1912. Ducker. Carburetor.
98. Oct. 14, 1913. Myers. Carburetor for household and other uses.
10. Feb. 8, 1916. Carpenter. Gas scrubber.
83. Feb. 8, 1916. Duckham. Vertical retort.
538. Mar. 28, 1916. Roberts. Carburetor.
924. Apr. 19, 1870. Kelly. Gas generator.
390. May 7, 1872. Bell. Improvement in apparatus for carbureting air.
,430. July 10, 1894. Vanorman. Carburetor.

Cross-reference patents, class 48, subclass 146.

)	356,476	483,489	576,499	780,355	942,863	962,860

Subclass 143, carburetors, heater.

Oct. 3, 1865. Irwin. Improved apparatus for carbureting air.
June 5, 1866. Tirrill. Improved gas apparatus.
Mar. 26, 1867. Clarke. Improved apparatus for carbureting air, etc.
Apr. 2, 1867. Hall. Improved apparatus for carbureting gas and air.
July 16, 1867. Barker & Gilbert. Improved apparatus for carbureting r and gas.
Aug. 3, 1869. Barker & Gilbert. Improved apparatus for carbureting r.
Aug. 3, 1869. Barker & Gilbert. Improved apparatus for carbureting r.
Sept. 21, 1869. Spang & Scheaf. Improved gas machine.
3. Aug. 15, 1871. Edgerton. Improvement in methods and apparatus r separating certain hydrocarbon vapors from illuminating gases.
l. May 21, 1872. Dayton. Improvement in apparatus for carbureting r.
l. Mar. 14, 1876. Porter & Grimes. Improvement in carburetors.
7. Apr. 11, 1876. Deeds. Improvement in air-gas machines.
5. May 2, 1876. Haymaker. Improvement in carbureting gas apparatus.
9. Feb. 26, 1876. Porter & Grimes. Carburetors.
3. Aug. 1, 1876. Randall & Boomer. Improvement in apparatus for aumatically regulating the temperature of carburetors.
49. Nov. 7, 1876. Ofeldt. Improvement in automatic heat regulators r gas machines.
08. Jan. 14, 1879. Pierce. Improvement in thermostats for carburetors.
30. Nov. 18, 1879. Jones. Improvement in air-carbureting apparatus r railroad cars.
22. Nov. 20, 1883. Copeland. Carburetor.
33. Apr. 5, 1887. Langdon. Apparatus for making gas.
09. Oct. 1, 1889. Hamlin. Gas enricher.
22. Feb. 25, 1890. Strouse. Carburetor.
97. May 6, 1890. Shannon. Carburetor.
72. July 4, 1893. Marcus. Carbureting apparatus.
18. July 3, 1894. Iles. Carburetor.
13. Aug. 25, 1896. Schrader. Carburetor.

613,167. October 25, 1898. Martenette. Carburetor.
*638,529. Dec. 5, 1899. Vanduzen. Vaporizer for explosive engines.
643,306. Feb. 13, 1900. Rey. Carburetor.
658,020. Sept. 18, 1900. Rey. Carburetor.
661,660. Nov. 13, 1900. Griebel. Carburetor.
*665,496. Jan. 8, 1901. Worth. Carburetor.
*694,110. Feb. 25, 1902. Sanson. Carburetor for explosive engines.
*696,231. Mar. 25, 1902. Fillet. Carbureting device for explosion engines.
*705,021. July 22, 1902. Bennett & Moorwood. Carburetor.
720,336. Feb. 10, 1903. Ede. Vaporizer for gasoline engines.
*733,625. July 14, 1903. Clement. Carburetor for motor bicycles.
*746,119. Dec. 8, 1903. Longuemare et al. Carburetor for explosive motors.
749,768. Jan. 19, 1904. Wilson. Apparatus for producing carbureted air.
*762,707. June 14, 1904. Grove. Carburetor for internal-combustion engines.
772,673. Oct. 18, 1904. Roebuck & McMillan. Carburetor.
*778,988. Jan. 3, 1905. Merritt. Carburetor.
*781,936. Feb. 7, 1905. Cook. Carburetor for hydrocarbon engines.
784,599. Mar. 14, 1905. Studabaker. Carburetor.
*799,232. Sept. 12, 1905. Gossé. Carburetor.
*800,777. Oct. 3, 1905. Westmacott. Carburetor and vaporizer for explosion engines.
842,170. Jan. 29, 1907. Bryant & Watling. Carburetor.
846,680. Mar. 12, 1907. Mason & Sinclair. Gas machine.
857,064. June 18, 1907. Holgate. Carbureting lamp.
894,389. July 28, 1908. Louis. Carburetor for explosion engines.
904,203. Nov. 17, 1908. Hertzberg & Low. Fuel heater for explosive engines.
906,548. Dec. 15, 1908. McCarthy. Carburetor.
909,896. Jan. 19, 1909. Hertzberg & Low. Electric vaporizer for internal-combustion engines.
920,721. May 4, 1909. Bradley. Grass burner for railway tracks.
*954,905. Apr. 12, 1910. Wolf. Carburetor.
957,786. May 10, 1910. Low, Wohl & Hertzberg. Vaporizing device.
962,860. June 28, 1910. Sanders. Carburetor.
*964,657. July 19, 1910. Lamb. Vaporizer for hydrocarbon engines.
990,249. Apr. 25, 1911. Garcia & Hertzberg. Starting vaporizer for explosive engines.
1,011,641. Dec. 12, 1911. Paterson. Carburetor.
*1,013,983. Jan. 9, 1912. Blom. Carburetor.
*1,014,945. Jan. 16, 1912. Brockhurst. Means for feeding and mixing fluids.
*1,043,342. Nov. 5, 1912. Musgrave. Carburetors for gas engines.
*1,061,626. May 13, 1913. Mowbray. Carburetor.
*1,065,640. June 24, 1913. Thompson. Fuel-vaporizing device.
*1,065,948. July 1, 1913. Lion. Carburetor.
*1,072,875. Sept. 9, 1913. Sammons. Carburetor mechanism.
1,091,784. Mar. 31, 1914. Weber. Carburetor.
1,095,555. May 5, 1914. Crone. Mixing unit for fluids.
*1,099,086. June 2, 1914. Hamilton. Carburetor.
1,102,309. July 7, 1914. Whiting. Heater for gaseous fuel.
1,102,478. July 7, 1914. Crowder. Gaseous-fuel heater.
1,107,489. Aug. 18, 1914. Bunn & Robinson. Carburetor.
1,107,967. Aug. 18, 1914. Knaak. Heater for internal-combustion engines.
1,109,025. Sept. 1, 1914. Taylor. Fuel heater.
1,114,200. Oct. 20, 1914. Stewart. Throttle for carburetors.
1,117,414. Nov. 17, 1914. Manning. Fuel heater.
*1,118,126. Nov. 24, 1914. Harroun. Carburetor.
1,120,352. Dec. 8, 1914. Wolf. Carburetor.
*1,122,703. Dec. 29, 1914. Dull. Carburetor.
1,128,998. Feb. 16, 1915. Mulvaney. Heater for gaseous fuel.
1,129,794. Feb. 23, 1915. Cummings. Carburetor.
*1,130,502. Mar. 2, 1915. Francisco. Carburetor.
*1,133,452. Mar. 30, 1915. Babbitt & Beaumont. Carburetor.
*1,133,527. Mar. 30, 1915. Bennett. Carburetor.
1,134,366. Apr. 6, 1915. Barnes. Carburetor.
1,136,675. Apr. 20, 1915. Hutchinson. Carburetor.
1,137,219. Apr. 27, 1915. Leake. Heater and attachment for motors.
1,140,064. May 18, 1915. Rakestraw. Carburetor.
1,141,570. June 1, 1915. McCornack. Carburetor.

1,142,824. June 15, 1915. Lund. Carburetor attachment.
1,148,247. July 27, 1915. Moore. Carburetor.
1,150,115. Aug. 17, 1915. Heinze. Carburetor.
1,150,619. Aug. 17, 1915. Percival & Patterson. Kerosene carburetor.
1,155,726. Oct. 5, 1915. Harroun. Carburetor.
1,156,836. Oct. 12, 1915. Diener. Carburetor.
1,158,494. Nov. 2, 1915. Harroun. Carburetor.
*1,159,933. Nov. 9, 1915. Grove. Carburetor.
1,160,585. Nov. 16, 1915. Edison. Fuel-supplying means.
*1,166,173. Dec. 28, 1915. Biays. Carburetor.
*1,167,457. Jan. 11, 1916. Wickersham. Carburetor.
*1,169,340. Jan. 25, 1916. Meara. Carburetor.
1,169,573. Jan. 25, 1916. Schultz. Vaporizer.
*1,172,397. Feb. 22, 1916. Schulz. Carburetor.
1,173,469. Feb. 29, 1916. White. Carburetor.
*1,176,816. Mar. 28, 1916. Hampton de Fontaine. Kerosene carburetor.
*1,177,940. Apr. 4, 1916. Ford. Carburetor.
*1,178,530. Apr. 11, 1916. Lytle, Klawiter, Kritch. Carburetor.
*1,182,714. May 9, 1916. Schmidt. Carburetor.
1,189,797. July 4, 1916. Deppé. Heater and mixer for internal-combustion engines.
1,187,375. June 13, 1916. O'Connor. Carburetor.

Cross-reference patents, class 48, subclass 148.

9,967	162,848	356,950	622,489	777,908	1,016,741	1,124,724
12,535	163,323	360,240	629,581	837,984	1,017,750	1,126,218
13,010	167,170	367,936	639,336	842,846	1,023,402	1,143,092
57,788	168,048	376,248	640,695	843,554	1,036,812	1,149,291
57,812	168,290	377,607	659,987	890,970	1,046,344	1,152,134
62,856	206,196	405,747	671,042	892,726	1,049,417	1,160,837
64,382	206,402	427,225	673,365	894,656	1,056,760	1,160,897
80,404	213,351	435,856	674,812	949,140	1,079,338	1,163,223
80,918	221,942	464,779	680,961	957,731	1,079,947	1,168,782
90,445	307,132	563,541	688,408	959,745	1,095,402	Re. 1,819
94,898	308,796	564,429	692,255	973,602	1,105,371	Re. 6,865
97,748	309,467	568,672	714,117	976,885	1,106,935	Re. 10,358
109,568	320,460	590,893	715,398	979,409	1,117,354	
127,031	348,917	620,586	716,227	994,574	1,119,479	
141,968	353,499	622,008	737,738	1,004,329	1,124,706	

SUBCLASS 149, CARBURETORS, HEATER, AIR.

26,070. Nov. 8, 1859. Kitchen. Apparatus for heating hydrocarbon liquids.
47,257. Apr. 11, 1865. Irwin. Improved process for carbureting air.
53,482. Mar. 27, 1866. Pond & Richardson. Improved gas apparatus.
57,639. Aug. 23, 1866. Rowley, Sloane et al. Improved apparatus for carbureting air.
66,622. July 9, 1867. Pedrick. Improvement in carbureting air.
76,880. Apr. 21, 1868. Barker. Improvement in apparatus for carbureting air.
79,667. July 7, 1868. Marshall. Improved air carburetor.
96,073. Oct. 26, 1869. Barbarin Improved machine for carbureting atmospheric air.
97,283. Nov. 30, 1869. Dunderdale. Improved apparatus for carbureting air.
110,946. Jan. 10, 1871. Works & Daniels. Improvement in apparatus and processes for generating and burning vapor fuel.
140,105. June 17, 1873. Wilkinson. Improvement in carburetors.
155,974. Oct. 13, 1874. Rand. Improvement in carburetors.
167,170. Aug. 31, 1875. Harrington. Improvement in carburetors.
187,415. Feb. 13, 1877. Rand. Improvement in apparatus for carbureting air.
198,150. Dec. 11, 1877. Porter. Improvement in plastic jacket and condenser for carburetors.
220,685. Oct. 14, 1879. Weart. Improvement in carbureting apparatus.
311,493. Feb. 3, 1885. James. Apparatus for generating gas.
403,839. May 21, 1889. Harvey. Furnace and apparatus for producing and burning gaseous vapors.
*531,779. Jan. 1, 1895. Cook. Carburetor.

633,320. Sept. 19, 1899. Inman. Carburetor.
672,854. Apr. 23, 1901. Goldsmith. Carburetor.
*685,993. Nov. 5, 1901. Le Blom. Carburetor for explosive engines.
689,460. Dec. 24, 1901. Clark & Cothran. Carburetor.
*741,810. Oct. 20, 1903. Mohler. Constant-level liquid-hydrocarbon vaporizer for oil engines.
768,801. Aug. 30, 1904. Hooker. Carburetor.
831,374. Sept. 18, 1906. Perrier. Apparatus for the production of carbureted air.
906,276. Dec. 8, 1908. Peregrine. Apparatus for carbureting air.
*1,017,572. Feb. 13, 1912. Lund. Attachment for carburetors.
1,065,819. June 24, 1913. Lion. Device for carbureting air.
1,066,295. July 1, 1913. Lion. Device for carbureting air.
1,091,521. Mar. 31, 1914. Lund. Temperature controller for carburetors.
1,113,892. Oct. 13, 1914. Feller. Carburetor.
1,132,199. Mar. 16, 1915. McKeen. Air heater for carburetors.
1,139,081. May 11, 1915. Stone. Fuel economizer for internal-combustion engines.
1,141,450. June 1, 1915. Erickson. Device for supplying heated air to carburetors.
*1,145,476. July 6, 1915. Fulton. Carburetor.
Re. 2,455. Jan. 15, 1867. Pond & Richardson. Improved gas apparatus.

Cross-reference patents, class 48, subclass 149.

52,087	175,827	435,856	723,487	1,004,329	1,070,449	1,132,420
90,436	221,942	478,549	742,920	1,011,641	1,072,875	1,158,494
100,080	254,243	505,700	911,967	1,013,983	1,107,967	
127,031	309,467	590,893	921,934	1,046,344	1,109,025	
162,848	370,936	673,365	951,501	1,064,106	1,120,128	
166,602	427,225	714,117	961,481	1,064,866	1,125,339	

SUBCLASS 150, CARBURETORS, OIL FEED.

58,422. Oct. 2, 1866. Hutchinson. Improved automatic feed for carburetors.
68,231. Aug. 27, 1867. Peacock. Improved carbureting apparatus.
81,590. Sept. 1, 1868. Brin. Approved apparatus for carbureting air and applying the same.
97,748. Dec. 7, 1869. Springer. Improved gas machine.
108,005. Oct. 4, 1869. Chapin. Improvement in apparatus for carbureting air and gas.
111,175. Jan. 24, 1871. Chapin. Improvement in apparatus for carbureting air.
190,714. May 15, 1877. Enggren. Improvement in gas carburetors.
198,353. Dec. 18, 1877. Chollar. Improvement in automatic feed regulators for carburetors.
212,502. Feb. 18, 1879. Reed. Improvement in feed regulators for carburetors.
230,744. Aug. 3, 1880. Chace. Gas governor and regulator for carburetors.
253,713. Feb. 14, 1882. Jackson. Oil-distributing mechanism for carburetors.
443,214. Dec. 23, 1890. Addicks. Heater for hydrocarbon liquids.
568,944. Oct. 6, 1896. Griffen. Device for charging hydrocarbon-gas generators.
679,018. July 23, 1901. Fischer. Oil feed for carburetors.
772,791. Oct. 18, 1904. Dow. Carburetor.
*792,670. June 20, 1905. Shain. Vaporizer or carburetor for gas engines.
810,087. Jan. 16, 1906. Sanders. Carburetor.
817,592. Apr. 10, 1906. Shiess. Carburetor.
820,554. May 15, 1906. Colbath. Carburetor.
834,029. Oct. 23, 1906. Smith. Carburetor.
835,745. Nov. 13, 1906. Bouchaud-Praceiq. Automatic apparatus for carbureting air and other gases.
855,407. May 28, 1907. Loewenstein. Carburetor.
866,587. Sept. 17, 1907. Johnson. Gas machine.
876,678. Jan. 14, 1908. Andres. Carburetor.
*894,225. July 28, 1908. O'Neill. Explosive engine.

912,468. Feb. 16, 1909. Grandjean. Oil feed for carbureting apparatus.
913,857. Mar. 2, 1909. Steward. Carburetor.
929,135. July 27, 1909. Osgrig. Carburetor.
934,366. Sept. 14, 1909. Steel. Means for supplying oil to carburetors.
951,779. Mar. 8, 1910. French. Carburetor.
975,156. Nov. 8, 1910. Piéplu. Carburetor.
984,032. Feb. 14, 1911. Seager. Carburetor.
1,063,081. May 27, 1913. Thiem. Apparatus for the production of air gas.
*1,110,131. Sept. 8, 1914. Green. Automatic regulator of carburetors.
*1,133,872. Mar. 30, 1915. Maness. Gas-engine attachment.
*1,137,135. Apr. 27, 1915. Hart. Carburetor.
*1,163,393. Dec. 7, 1915. Corbett. Carburetor.
Re. 6,070. Jan. 24, 1871. Chapin. Improvement in carburetors.

Cross-reference patents, class 48, subclass 150.

93,267	320,460	763,074	783,790	923,377	944,482	979,761
114,358	333,508	775,859	794,938	932,478	948,744	1,002,791
135,806	589,094	777,390	818,207	949,140	962,860	1,046,658
169,084	592,579	782,788	818,397	953,606	964,165	1,089,471
211,194	758,790	782,980	823,382	940,916	976,781	1,137,219
219,158						

SUBCLASS 150.1, CARBURETORS, OIL FEED, MULTIPLE SUPPLY.

683,125. Sept. 24, 1901. Laurent & Clerget. Vaporizing device for explosive engines.
*684,662. Oct. 15, 1901. Ahara. Feeder for explosive engines.
*756,879. Apr. 12, 1904. McCadden. Carburetor for internal-combustion engines.
*771,492. Oct. 4, 1904. Parmenter. Carburetor for explosive engines.
798,150. Aug. 29, 1905. Wolgamott. Carburetor for gas engines.
*811,618. Feb. 6, 1906. Claudel. Carburetor for hydrocarbon engines.
*871,288. Nov. 19, 1907. Merwin. Gas-saturating device.
*877,890. Jan. 28, 1908. Gerber & Weiland. Vaporizer.
*907,953. Dec. 29, 1908. Baverey. Carburetor for explosion motors.
923,093. May 25, 1909. Wegner. Gasoline engine.
943,684. Dec. 21, 1909. Johnston. Vaporizer for internal-combustion engines.
977,066. Nov. 29, 1910. Blow. Carburetor.
982,826. Jan. 31, 1911. Johnston. Mixing valve for internal-combustion engines.
983,994. Feb. 14, 1911. Harrington. Carburetor.
*1,003,351. Sept. 12, 1911. Fulton. Carburetor.
*1,013,759. Jan. 2, 1912. Freidag. Internal-combustion engine.
*1,021,326. Mar. 26, 1912. Mowbray. Hydrocarbon vaporizer for internal-combustion engines.
1,029,740. June 18, 1912. Beck. Carbureting apparatus for explosive engines.
1,038,780. Sept. 17, 1912. Moore & Browne. Engine.
1,043,080. Nov. 5, 1912. Duis. Moisture-supplying device for carbureted air.
1,048,620. Dec. 31, 1912. Williams. Carburetor.
*1 055,084. Mar. 4, 1913. Rumely. Carburetor.
*1,062,333. May 20, 1913. Higgins. Carburetor.
*1,069,399. Aug. 5, 1913. Eckre. Carburetor.
*1,077,910. Nov. 4, 1913. Higgins. Carburetor.
*1,084,151. Jan. 13, 1914. Ireland. Carburetor.
*1,085,239. Jan. 27, 1914. Bischop. Bifuel carburetor.
*1,095,384. May 5, 1914. Collett. Carburetor.
*1,095,622. May 5, 1914. Bruun. Carburetor.
*1,099,277. June 9, 1914. Baverey. Carburetor.
*1,099,547. June 9, 1914. Gentle. Carburetor.
*1,101,147. June 23, 1914. Sawyer. Admission valve.
*1,102,722. July 7, 1914. Cobb. Carburetor.
*1,104,762. July 28, 1914. Ahlberg. Carburetor.
*1,108,181. Aug. 25, 1914. Kane. Carburetor.
*1,111,224. Sept. 22, 1914. Hamilton. Carburetor.
*1,112,641. Oct. 6, 1914. Moeller. Fluid mixing and regulating device.

1,120,602. Dec. 8, 1914. Corser. Carburetor.
*1,121,651. Dec. 22, 1914. Mohler & Fry. Carbureting apparatus.
*1,124,724. Jan. 12, 1915. Gentle. Carburetor.
*1,132,580. Mar. 23, 1915. Hazen. Carburetor.
*1,137,135. Apr. 27, 1915. Hart. Carburetor.
*1,138,829. May 11, 1915. Ahlberg. Carburetor.
*1,141,258. June 1, 1915. Noyes. Liquid feeder for burners, etc.
*1,142,793. June 15, 1915. Baker. Carburetor.
*1,143,961. June 22, 1915. Haynes. Carburetor.
*1,145,990. July 15, 1915. Higgins. Carburetor.
*1,150,202. Aug. 17, 1915. Johnston & Longenecker. Carburetor.
*1,150,224. Aug. 17, 1915. Podlesak. Internal-combustion engines.
*1,152,134. Aug. 31, 1915. Webb. Carburetor.
*1,153,436. Sept. 14, 1915. McCray. Carburetor.
*1,154,630. Sept. 28, 1915. Higgins. Carburetor.
*1,155,407. Oct. 5, 1915. Dougan. Carburetor.
*1,157,116. Oct. 19, 1915. Maing & Pellegrini. Carburetor.
*1,160,239. Nov. 16, 1915. Bates. Carburetor.
*1,163,393. Dec. 7, 1915. Corbett. Carburetor.
*1,166,734. Jan. 4, 1916. Anderson. Carburetor.
*1,166,967. Jan. 4, 1916. Burger. Fuel-feed mechanism for internal-combustion engines.
*1,168,783. Jan. 18, 1916. Bucker. Carburetor.
*1,171,200. Feb. 8, 1916. Holley. Carburetor.
*1,172,263. Feb. 22, 1916. Fontaine. Carburetor for kerosene and the like.
*1,176,600. Mar. 21, 1916. Radloff. Carburetor.
*1,177,538. Mar. 28, 1916. Roberts. Carburetor.
*1,179,278. Apr. 11, 1916. Carithers. Carburetor.
*1,183,221. May 16, 1916. Miller & Adamson. Carburetor.
*1,183,293. May 16, 1916. Gilles. Carburetor.

Cross-reference patents, class 48, subclass 150.1.

439,813	672,500	812,860	944,811	983,307	1,098,164	1,140,064
575,720	698,895	817,721	961,152	995,530	1,109,025	1,148,898
581,930	706,050	830,144	964,409	1,013,983	1,110,482	1,156,836
593,911	726,671	852,272	976,237	1,022,027	1,111,897	Re. 12,322
625,887	778,988	867,797	979,667	1,065,948	1,116,192	
632,859	801,390	878,706	979,787	1,072,875	1,128,998	
668,953	807,391	906,783	980,946	1,077,414	1,133,527	

SUBCLASS 150.2, CARBURETORS, OIL FEED, MULTIPLE JET.

498,673. May 30, 1893. Mulvey. Apparatus for carbureting air.
*616,974. Jan. 3, 1899. Riotte. Gas engine.
716,573. Dec. 23, 1902. Nelk. Carburetor for explosive engines.
*726,986. May 5, 1903. Peteler. Carburetor for gas engine.
*751,292. Feb. 2, 1904. Johanson. Mixer for gasoline engines.
*792,878. June 20, 1905. Brasier. Carburetor.
*823,485. June 12, 1906. Steinbrenner & Mayer. Carburetor for explosive engines.
*867,859. Oct. 8, 1907. Weinat & Bogey. Carburetor.
*871,134. Nov. 19, 1907. Monnier & Morin. Carburetor.
*891,322. June 23, 1908. Brennan. Carburetor for explosive engines.
*894,656. July 28, 1908. Johnston. Carburetor for internal-combustion engines.
*952,547. Mar. 22, 1910. Schwartz. Carburetor.
*973,602. Oct. 25, 1910. Williams. Carburetor.
*977,813. Dec. 6, 1910. Marrder. Carburetor.
*979,908. Dec. 27, 1910. Willet. Carburetor.
985,256. Feb. 28, 1911. Friedenwald. Carburetor.
*986,700. Mar. 14, 1911. Fogel. Carburetor.
*995,074. June 13, 1911. McCarthy. Priming attachment for carburetors.
*995,919. June 20, 1911. Smith. Carburetor.
*997,929. July 11, 1911. Meyer. Carburetor.
*1,117,233. Nov. 17, 1914. Barker. Carburetor.

*1,118,805. Nov. 24, 1914. Reichenbach. Carburetor.
*1,143,092. June 15, 1915. Unckles. Carburetor.
*1,143,779. June 22, 1915. Pembroke. Carburetor.
*1,147,644. July 20, 1915. Reichenbach. Carbureting device.
*1,151,989. Aug. 31, 1915. Balassa. Carburetor.
*1,158,435. Nov. 2, 1915. Bourne. Carburetor.
*1,160,837. Nov. 16, 1915. Burnham. Carburetor.
*1,167,217. Jan. 4, 1916. Reichenbach. Carburetor.
*1,176,267. Mar. 21, 1916. Baverey. Carburetor.
*1,179,701. Apr. 18, 1916. Costa. Carburetor.
*1,180,152. Apr. 18, 1916. Howes. Carburetor.
*1,184,695. May 23, 1916. Costa. Carburetor.
*1,186,797. June 13, 1916. Kingston. Carburetor.

Cross-reference patents, class 48, subclass 150.2.

504,723	696,146	842,261	938,894	1,118,126	1,165,656	1,169,573
568,017	741,810	852,272	1,106,258	1,134,366	1,168,782	

SUBCLASS 150.3, CARBURETORS, OIL FEED, MULTIPLE JET, PROGRESSIVE.

*664,184. Dec. 18, 1900. Dougill. Internal-combustion engine.
*674,034. May 14, 1901. Krastin. Speed governor for explosive engines.
*755,074. Mar. 22, 1904. Sturtevant. Double carburetors for explosive engines.
*759,624. May 10, 1904. MacMulkin. Vaporizer for hydrocarbon engines.
*818,858. Apr. 24, 1906. Renault. Carburetor.
*832,183. Oct. 2, 1906. Duryea & Remington. Carburetor.
*832,184. Oct. 2, 1906. Duryea & Remington. Carburetor.
*851,759. Apr. 30, 1907. Kunkel. Carburetor.
*858,437. July 2, 1907. Brooke. Carburetor.
*871,320. Nov. 19, 1907. Bollée. Carburetor.
*871,741. Nov. 19, 1907. Sturtevant. Double carburetor for explosive engines.
*879,380. Feb. 18, 1908. Greuter. Multiple carburetor.
*881,416. Mar. 10, 1908. Krebs. Carburetor.
*881,800. Mar. 10, 1908. Horstman. Carburetor for internal-combustion engines.
*891,219. June 16, 1908. Menns. Carburetor.
*892,499. July 7, 1908. Broderick. Carburetor.
*895,709. Aug. 11, 1908. Abernethy. Carburetor for hydrocarbon engines.
*898,494. Sept. 15, 1908. Mooers. Carburetor.
*898,495. Sept. 15, 1908. Mooers. Carburetor.
*900,604. Oct. 6, 1908. Small. Carburetor.
*901,845. Oct. 20, 1908. Howell. Carburetor.
*907,757. Dec. 29, 1908. Duryea. Carburetor.
*910,018. Jan. 19, 1909. Prestwich. Carburetor for internal-combustion engines.
*920,979. May 11, 1909. Morehouse. Carburetor.
*927,211. July 6, 1909. Bennett. Carburetor.
*928,121. July 13, 1909. Goldberg. Carburetor.
*932,465. Aug. 31, 1909. Haas. Carburetor.
*941,424. Nov. 30, 1909. Leonard. Carburetor.
*948,612. Feb. 8, 1910. Krause. Carburetor for combustion engines.
*954,785. Apr. 12, 1910. Craven. Carburetor.
*958,476. May 17, 1910. Cook. Carburetor.
*961,481. June 14, 1910. Carter. Carburetor.
*970,558. Sept. 20, 1910. Ryan. Carburetor.
*973,262. Oct. 18, 1910. Daniel. Carburetor.
*976,258. Nov. 22, 1910. Gallagher. Carburetor.
*977,044. Nov. 29, 1910. Rebourg. Carburetor.
*979,700. Dec. 27, 1910. Proehl. Carburetor.
*982,297. Jan. 24, 1911. Perce. Carburetor.
*982,428. Jan. 24, 1911. Huggins & Parker. Carburetor.
*989,307. Apr. 11, 1911. Simmons. Carburetor.
*989,515. Apr. 11, 1911. Sprung & Rose. Carburetor.
*993,770. May 30, 1911. Fritz. Carburetor.

*998,123. July 18, 1911. Scaife. Carburetor.
*1,001,950. Aug. 29, 1911. Hart. Carburetor.
*1,002,699. Sept. 5, 1911. Jouffret & Renée. Carburetor.
*1,002,700. Sept. 5, 1911. Jouffret & Renée. Carburetor.
*1,006,130. Oct. 17, 1911. Riotte. Vaporizer.
*1,006,387. Oct. 17, 1911. Kreis. Carburetor.
*1,006,411. Oct. 17, 1911. Scott. Carburetor.
*1,010,051. Nov. 28, 1911. Hoffman. Carburetor.
*1,010,066. Nov. 28, 1911. Newcomb. Carburetor.
*1,010,116. Nov. 28, 1911. Carter. Carburetor.
*1,011,694. Dec. 12, 1911. Winton. Carburetor.
*1,011,696. Dec. 12, 1911. Winton. Carburetor.
*1,011,960. Dec. 19, 1911. Ionides. Carburetor.
*1,014,551. Jan. 9, 1912. Winton. Carburetor.
*1,016,108. Jan. 30, 1912. Steinbrenner. Carburetor.
*1,018,262. Feb. 20, 1912. Neal. Carburetor for internal-combustion engines.
*1,021,547. Mar. 26, 1912. Motsinger. Carburetor.
*1,022,702. Apr. 9, 1912. Rothe. Carburetor.
1,022,703. Apr. 9, 1912. Rothe. Carburetor.
*1,037,993. Sept. 10, 1912. Romans. Carburetor.
*1,038,040. Sept. 10, 1912. Weiss. Carburetor.
*1,040,414. Oct. 8, 1912. Rettig. Carburetor.
*1,040,619. Oct. 8, 1912. Carter. Carburetor.
*1,041,481. Oct. 15, 1912. Kaley. Carburetor.
*1,046,014. Dec. 3, 1912. Ratcliff. Carburetor.
*1,046,434. Dec. 10, 1912. Bolée. Carburetor.
*1,048,518. Dec. 31, 1912. Fritz. Priming device for carburetors.
*1,049,705. Jan. 7, 1913. Greuter. Carburetor.
*1,051,041. Jan. 21, 1913. White. Carburetor.
*1,061,835. May 13, 1913. Gobbi. Carburetor.
*1,063,148. May 27, 1913. Anderson. Carburetor.
*1,065,912. June 24, 1913. Binon. Carburetor.
*1,065,977. July 1, 1913. Smith. Carburetor.
*1,069,817. Aug. 12, 1913. Schultz. Carburetor.
*1,072,733. Sept. 9, 1913. Kaltenbach. Carburetor.
*1073,179. Sept. 16, 1913. Sprung. Carburetor.
*1,074,574. Sept. 30, 1913. Riotte. Carburetor.
*1,074,575. Sept. 30, 1913. Riotte. Carburetor.
*1,074,577. Sept. 30, 1913. Smith. Carburetor.
*1,078,349. Nov. 11, 1913. Hawzhurst & Nicolai. Carbureting device.
*1,078,582. Nov. 11, 1913. Jaugey. Carburetor.
1,079,634. Nov. 25, 1913. Burchartz. Carburetor.
*1,080,118. Dec. 2, 1913. Monosmith. Carburetor.
*1,080,815. Dec. 9, 1913. Everest. Carberetor for internal-combustion engines.
*1,088,091. Feb. 24, 1914. Raymond. Carburetor.
*1,089,089. Mar. 3, 1914. Stamps. Carburetor.
*1,089,105. Mar. 3, 1914. Bessom & Anderson. Carburetor.
*1,089,372. Mar. 3, 1914. Baverey. Carburetor for internal-combustion engines.
*1,089,524. Mar. 10, 1914. Barrett & Wilson. Carburetor.
*1,090,047. Mar. 10, 1914. Goudard & Mennesson. Carburetor.
*1,090,208. Mar. 17, 1914. Heitger. Carburetor.
*1,093,343. Apr. 14, 1914. McAndrews. Carburetor.
*1,094,674. Apr. 28, 1914. Miller & Adamson. Carburetor.
*1,099,293. June 9, 1914. Goldberg & Tillotson. Carburetor.
1,099,828. June 9, 1914. Tatom. Carburetor.
*1,100,679. June 16, 1914. McGuire. Carburetor.
*1,101,869. June 30, 1914. McGuire. Carburetor.
*1,103,930. July 21, 1914. Bennett. Carburetor.
*1,104,560. July 21, 1914. Shoobridge & Gunstone. Carburetor.
1,106,192. Aug. 4, 1914. Crouan. Carburetor.
*1,108,245. Aug. 25, 1914. Schebler. Carburetor.
*1,109,974. Sept. 8, 1914. Fagard. Carburetor for internal-combustion engines.
*1,112,374. Sept. 29, 1914. Livingston. Carburetor.
*1-,113,221. Oct. 13, 1914. Krause Carburetor.

13,551. Oct. 13, 1914. Greuter. Carburetor.
5,632. Nov. 3, 1914. Weiss. Device for regulating supplemental supply of fuel mixtures and air to internal-combustion engines.
16,023. Nov. 3, 1914. Crawford. Carburetor.
19,076. Dec. 1, 1914. Frey. Carburetor.
20,183. Dec. 8, 1914. Duff. Carburetor.
20,184. Dec. 8, 1914. Duff. Carburetor.
20,185. Dec. 8, 1914. Duff. Carburetor.
22,571. Dec. 29, 1914. Binks. Carburetor.
23,469. Jan. 5, 1915. Bennett. Carburetor.
24,697. Jan. 12, 1915. Carter. Needle-valve operating mechanism for carburetors.
25,069. Jan. 19, 1915. Coulter. Carburetor.
25,368. Jan. 19, 1915. Monosmith. Carburetor.
28,773. Feb. 16, 1915. Goldberg. Carburetor.
30,350. Mar. 2, 1915. Thompson. Carburetor.
30,474. Mar. 2, 1915. Brush. Carburetor.
30,490. Mar. 2, 1915. Delaunay-Belleville. Carburetor.
30,700. Mar. 9, 1915. Bennett. Carburetor.
30,950. Mar. 9, 1915. Williams. Carburetor.
33,904. Mar. 30, 1915. Wyman. Carburetor.
34,942. Apr. 6, 1915. Bessom & Anderson. Carburetor.
35,211. Apr. 13, 1915. Schiedeknecht. Carburetor.
43,986. June 22, 1915. Muir. Carburetor.
44,206. June 22, 1915. Juhász. Carburetor.
45,824. July 6, 1915. Udale. Carburetor.
46,150. July 13, 1915. Gardner. Visible carburetor.
47,337. July 20, 1915. Muir. Carburetor.
47,940. July 27, 1915. Griffin. Carburetor.
48,378. July 27, 1915. Grapin. Carburetor.
48,485. July 27, 1915. Gallagher. Carburetor.
49,291. Aug. 10, 1915. Richard. Carburetor.
51,778. Aug. 31, 1915. Funderburk. Carburetor.
52,031. Aug. 31, 1915. Lobdell. Carburetor.
52,173. Aug. 31, 1915. Haugele. Carburetor.
53,487. Sept. 14, 1915. Greiner. Carburetor.
55,457. Oct. 5, 1915. Wetterhahn. Carburetor.
56,084. Oct. 12, 1915. Kimmell. Carburetor.
57,146. Oct. 19, 1915. Carrel. Pressure carburetor.
58,589. Nov. 2, 1915. Thurot. Carburetor.
59,167. Nov. 2, 1915. Breeze. Carburetor.
59,851. Nov. 9, 1915. McCurdy. Carburetor.
62,041. Nov. 30, 1915. Cunningham. Carburetor.
62,308. Nov. 30, 1915. Pond. Carburetor.
62,680. Nov. 30, 1915. Buick. Carburetor.
63,223. Dec. 7, 1915. Deppé. Carburetor.
64,661. Dec. 21, 1915. Muir. Carburetor.
26,159. Jan. 26, 1915. Dressel. Floatless carburretor.
66,308. Dec. 28, 1915. Arquembourg. Carburetor.
68,513. Jan. 18, 1916. Kingston. Carburetor.
69,616. Jan. 25, 1916. Carter. Carburetor.
70,348. Feb. 1, 1916. Schüttler. Starting and idle-running device for jet carburetors.
70,416. Feb. 1, 1916. Claudel. Carburetor.
70,417. Feb. 1, 1916. Claudel. Carburetor.
71,074. Feb. 8, 1916. Stroud. Carburetor.
72,031. Feb. 15, 1916. Morand. Carburetor.
72,701. Feb. 22, 1916. Gardner. Carburetor.
73,246. Feb. 29, 1916. Boettcher. Carburetor.
75,536. Mar. 14, 1916. Longuemare. Carburetor.
76,516. Mar. 21, 1916. Boyce. Carburetor.
76,627. Mar. 21, 1916. Ver Planck. Carburetor.
76,651. Mar. 21, 1916. Chatain. Carburetor.
77,624. Apr. 4, 1916. Hill. Carburetor.
78,832. Apr. 11, 1916. Augustine. Fluid-mixing device.
79,381. Apr. 11, 1916. Sunderman. Carburetor.

*1,180,483. Apr. 25, 1916. Fogolin. Carburetor.
*1,180,518. Apr. 25, 1916. Malstrom & Andersen. Carburetor.
*1,180,976. Apr. 25, 1916. Cloudsley. Carburetor.
*1,181,128. May 2, 1916. Fritz. Automatic priming device for carburetors.
*1,183,019. May 16, 1916. McGuire. Carburetor.
*1,183,081. May 16, 1916. Krueger. Carburetor.
*1,183,183. May 16, 1916. Funderburk. Combined dash adjustment and primer for carburetors.
*1,183,222. May 16, 1916. Miller. Carburetor.
*1,183,294. May 16, 1916. Gilles. Carburetor.
*1,183,587. May 16, 1916. Parkin. Carburetor.
*1,183,673. May 16, 1916. Robertson. Carburetor.
*1,184,267. May 23, 1916. Smith. Carburetor.
*1,184,923. May 30, 1916. Carter. Carburetor.
*1,185,016. May 30, 1916. Spiller. Carburetor.
*1,185,492. May 30, 1916. Finch. Carburetor.
*1,190,573. July 11, 1916. Nedoma. Carburetor.
*Re. 12,611. Feb. 19, 1907. Sturtevant. Double carburetor for explosive engines.
*Re. 13,580. June 24, 1913. Fritz. Priming device for carburetors.
*1,186,371. June 6, 1916. Baverey. Carburetor.
*1,187,463. June 13, 1916. Merriam. Carburetor.
*1,188,390. June 27, 1916. Baverey. Carburetor.
*Re. 14,045. Jan. 11, 1916. Heftler. Carburetor.

Cross-reference patents, class 48, subclass 150.3.

710,841	961,423	1,055,352	1,098,164	1,116,673	1,120,763	1,158,494
842,261	991,152	1,069,502	1,107,849	1,119,078	1,145,138	1,177,318
844,894	1,038,921	1,096,482	1,115,951			

SUBCLASS 151, CARBURETORS, OIL FEED, FLOAT VALVES.

45,729. Jan. 3, 1865. McDougall. Improved apparatus for carbureting gases.
55,324. June 5, 1866. McDougall. Improved apparatus for carbureting air.
57,551. Aug. 28, 1866. Myer. Improved apparatus for generating illuminating gas.
59,142. Oct. 23, 1866. Smith. Feeder for carburetors.
80,268. July 28, 1868. Boon & Perry. Improved apparatus for carbureting gas and air.
107,853. Oct. 4, 1868. Bartlett. Improvement in gas carburetors.
127,039. May 21, 1872. Fish. Improvement in carburetors.
131,815. Oct. 1, 1872. Drake. Improvement in apparatus for carbureting air and gas.
140,998. July 22, 1873. Fischer. Improvement in carburetors.
154,475. Aug. 25, 1874. Grimes. Improvement in gas-carbureting machines.
156,142. Oct. 20, 1874. Dillon. Improvement in gas machines for carbureting air.
156,463. Nov. 3, 1874. Marks. Improvement in carburetors.
158,184 Dec. 29, 1874. Porter. Improvement in apparatus for carbureting air and gas.
160,690. Mar. 2, 1875. Lockwood. Improvement in carburetors.
162,848. May 4, 1875. Ofeldt. Improvement in gas apparatus for carbureting air.
164,360. June 15, 1875. Bean. Improvement in carburetors.
166,476. Aug. 10, 1875. Porter. Improvement in gas carburetors.
168,048. Sept. 21, 1876. Porter & Grimes. Improvement in air and gas carburetors.
176,156. Apr. 18, 1876. Wiggin. Improvement in carburetors.
176,156. Apr. 18, 1876. Wiggin. Improvement in carburetors.
177,104. May 9, 1876. Deeds. Improvement in carburetors.
186,302. Jan. 16, 1877. Boomer & Randall. Improvement in gas and air carburetors.
189,645. Apr. 17, 1877. Palmer. Improvement in carburetors.
193,232. July 17, 1877. Drake. Improvement in carburetors.
193,911. Aug. 7, 1877. Bangs. Improvement in carburetors.
198,657. Dec. 25, 1877. Merritt. Improvement in regulated valves for carburetors.

199,055. Jan. 8, 1878. Gray. Improvement in feed regulators for carburetors.
199,781. Jan. 29, 1878. Bradley. Improvement in carburetors.
199,928. Feb. 5, 1878. Nelon. Improvement in carbureting apparatus.
206,196. July 23, 1878. Porter. Carburetor.
207,886. Sept. 10, 1878. Miner. Improvement in carburetors.
213,351. Mar. 18, 1879. Roth. Improvement in carburetors.
222,822. Dec. 23, 1879. Howard. Improvement in gas carburetors.
226,875. Apr. 27, 1880. Palmer. Gas carburetor.
233,978. Nov. 2, 1880. Burrows. Carbureting apparatus.
248,750. Oct. 25, 1881. Hughes. Gas carburetor.
280,746. July 3, 1881. Jackson. Metrical carburetor.
288,868. Nov. 20, 1883. Sauderson. Carburetor.
291,676. Jan. 8, 1884. Burrows. Apparatus for carbureting air.
301,790. July 8, 1884. Bagger. Carburetor.
303,927. Aug. 19, 1884. Froh. Carburetor.
308,886. Dec. 9, 1884. English. Apparatus for carbureting air or gases.
312,289. Feb. 17, 1885. Palmer. Air or gas carburetor.
317,686. May 12, 1885. Symons. Gas carburetor.
336,378. Feb. 16, 1886. Bennett. Automatic gas generator.
340,221. Apr. 20, 1886. Lawrence. Carburetor.
353,311. Nov. 30, 1886. Keller. Carburetor.
390,037. Sept. 25, 1888. Ruckle & Wolters. Carburetor.
395,152. Dec. 25, 1888. Lawrence. Carburetor.
403,377. May 14, 1889. Rogers & Wharry. Carburetor for gas engines.
427,225. May 6, 1890. Cooper. Carburetor.
528,882. Nov. 6, 1894. Keller. Carburetor.
575,901. Jan. 26, 1897. McKnight. Gasolene-gas machine.
583,126. May 25, 1897. Ryder. Carburetor.
583,818. June 1, 1897. Redmon. Carburetor.
586,923. July 20, 1897. Aldrich. Apparatus for manufacturing gas.
587,867. Aug. 10, 1897. Shaver. Carburetor.
595,658. Dec. 14, 1897. Seitz. Carburetor.
603,431. May 3, 1898. Pinckney. Carburetor.
607,888. July 26, 1898. Smith. Carburetor.
607,889. July 26, 1898. Smith. Carburetor.
618,108. Jan. 24, 1899. Lamb. Carburetor.
623,725. Apr. 25, 1899. Lange. Carburetor.
626,193. May 30, 1899. Small. Carburetor.
629,246. July 18, 1899. Grau. Carburetor.
639,336. Dec. 19, 1899. Anson. Carburetor.
640,695. Jan. 2, 1900. Parrott. Carburetor.
646,320. Mar. 27, 1900. Selzer. Carburetor.
657,770. Sept. 11, 1900. Hedrick. Carburetor.
663,683. Dec. 11, 1900. Royal. Carburetor.
685,787. Nov. 5, 1901. Myers. Carburetor.
688,776. Dec. 10, 1901. Greenamyer. Carburetor.
688,931. Dec. 17, 1901. Carter & Zierlein. Carburetor.
690,303. Dec. 31, 1901. Legge. Carburetor.
697,507. Apr. 15, 1902. Electrical condenser.
701,890. June 10, 1902. Keller. Carburetor.
706,454. Aug. 5, 1902. Robinson. Carburetor.
706,600. Aug. 12, 1902. Rush. Carburetor.
707,467. Aug. 19, 1902. Walther. Carburetor.
727,161. May 5, 1903. Leckband. Apparatus for carbureting air.
746,173. Dec. 8, 1903. Sayre. Carburetor.
754,774. Mar. 15, 1904. Jas. Carburetor.
828,334. Aug. 14, 1906. Peterson. Carburetor.
832,330. Oct. 2, 1906. Morrison. Carburetor.
844,996. Feb. 19, 1907. Colbath. Carburetor.
871,480. Nov. 19, 1907. Cornish. Carburetor.
885,832. Apr. 28, 1908. Breiding. Carburetor.
886,403. May 5, 1908. Puddington. Carburetor.
931,386. Aug. 17, 1909. Colbath. Carburetor.
954,258. Apr. 5, 1910. Colbath. Automatic valve for carburetors, etc.
Re. 6,865. Jan. 18, 1876. Porter & Grimes. Improvement in air and gas carburetors.

Cross-reference patents, class 48, subclass 151.

50,076	148,602	211,306	350,382	604,948	829,375	989,848
57,788	151,392	234,955	493,165	654,686	844,995	989,980
57,812	166,427	236,159	509,174	720,485	853,196	1,009,121
63,667	174,851	238,757	522,574	742,920	860,334	1,070,394
85,104	176,349	245,443	559,341	763,965	870,052	
103,036	180,061	246,601	568,672	780,673	883,171	
109,568	183,884	262,991	575,901	781,701	886,526	
125,194	198,731	280,747	583,126	783,648	900,731	
135,020	204,974	308,877	593,284	796,557	951,501	

SUBCLASS 152, CARBURETOR, OIL FEED, PUMPS.

169,843. Nov. 9, 1875. Rand. Improvement in carbureting apparatus.
439,579. Sept. 15, 1891. Hargreaves et al. Carburetor.
576,499. Feb. 2, 1897. Ransom. Gas apparatus.
622,008. Mar. 28, 1899. Kemp. Carburetor.
625,294. May 16, 1899. Egan. Carburetor.
646,780. Apr. 3, 1900. Wood. Carburetor.
665,568. Jan. 8, 1901. Kemp. Gas-generating apparatus.
670,599. Mar. 26, 1901. Tenney. Carburetor.
689,004. Dec. 17, 1901. Kemp. Carburetor.
692,518. Feb. 4, 1902. Jacks. Carburetor.
712,803. Nov. 4, 1902. Johnson. Carburetor.
731,137. June 16, 1903. Speer. Carbureting apparatus.
743,439. Nov. 10, 1903. Bower. Carburetor feed.
745,489. Dec. 1, 1903. Goslee. Carburetor.
762,477. June 14, 1904. Garde. Apparatus for carbureting air.
780,355. Jan. 17, 1905. Kelley. Carburetor.
927,558. July 13, 1904. Laux. Carburetor.
*1,119,479. Dec. 1, 1914. Veeder. Carburetor.
*1,149,323. Aug. 10, 1915. Baker & Swan. Apparatus for feeding fuel to oil engines.
*1,153,077. Sept. 7, 1915. Nippel. Carburetor.
1,164,093. Dec. 14, 1915. Houghton & Hall. Carburetor.

Cross-reference patents, class 48, subclass 152.

596,658	673,542	735,011	831,374	959,350	1,048,083	1,150,115
620,595	714,414	767,485	841,779	1,022,451	1,080,471	1,166,595
625,084						

SUBCLASS 153, CARBURETORS, OIL FEED, ROTARY.

49,448. Aug. 15, 1865. Simonds. Improved apparatus for carbureting air.
57,940. Sept. 11, 1866. McAvoy. Improved apparatus for carbureting air.
65,296. May 28, 1867. Stevens. Improved apparatus for carbureting air.
68,666. Sept. 10, 1867. Stevens. Improved combination apparatus for carbureting air.
82,244. Sept. 15, 1868. Plass. Improved apparatus for carbureting air.
85,972. Jan. 19, 1869. Steiner. Improved gas generator.
87,556. Mar. 9, 1869. Foster & Ganster. Improved gas apparatus.
97,122. Nov. 23, 1869. Root & Custer. Improved portable gas apparatus and carburetor.
102,784. May 10, 1870. Doty. Improvement in gas generators.
127,366. May 28, 1872. Pierson. Improvement in carburetors.
133,057. Dec. 17, 1872. Terry. Improvement in carburetors.
138,409. Apr. 29, 1873. Judd & Doty. Improvement in apparatus for carbureting air.
140,711. July 8, 1873. Judd & Pierson. Improvement in carbureting apparatus.
153,876. Aug. 4, 1874. Wilson et al. Improvement in carbureting apparatus.
155,297. Sept. 22, 1874. Denny & Pierson. Improvement in air carburetors.
168,290. Sept. 28, 1875. Schüssler. Improvement in hydrocarbon-gas apparatus.

). Apr. 10, 1877. Paquette. Improvement in carburetors.
. July 10, 1877. Pierson. Improvement in carbureting machines.
. July 30, 1878. Paquelin. Improvement in carbureting apparatus.
3. Nov. 8, 1881. Jackson. Metrical carburetor.
. Apr. 3, 1883. Ransom. Apparatus for carbureting gas.
. July 3, 1883. Jackson. Metrical regulator for distributing hydrorbon liquid to gas or air.
. Dec. 9, 1884. Copeland. Automatic hydrocarbon-feeding apparatus r carburetors.
. Dec. 16, 1884. Jackson. Bucket for measuring wheels of carburetors.
). Aug. 23, 1887. English & Stubbers. Gas machine.
. June 3, 1890. Hambleton. Apparatus for measuring and carbureting r or gas.
. June 4, 1895. Coleman. Gasoline-gas machine.
). July 21, 1896. Kemp. Air-gas machine.
. Sept. 5, 1899. Stanley. Carburetor.
. Oct. 1, 1901. Guy. Carburetor.
. Jan. 28, 1902. Martenette. Carburetor.
). Feb. 11, 1902. Kemp. Carburetor.
. Sept. 8, 1903. Carrissimo et al. Carbureting apparatus.
. July 18, 1905. Poole. Carbureting machine.
). Aug. 8, 1905. Guy. Oil feed for carburetors.
36. Apr. 27, 1915. Schmidt. Carbureting apparatus.
358. July 17, 1883. Paquelin. Carbureting apparatus.

Cross-reference patents, class 48, subclass 153.

,116	59,474	308,796	733,444	743,085	750,311	1,109,085

SUBCLASS 154, CARBURETORS, OIL FEED, SPRAY.

Mar. 21, 1865. Simonds. Improved apparatus for carbureting air.
June 27, 1865. Hainsworth. Improved apparatus for carbureting air.
Jan. 8, 1867. Williams. Improved method of carbureting gas.
. Mar. 20, 1883. Copeland. Carburetor.
. Apr. 21, 1885. Hayes. Apparatus for carbureting and odorizing tural gas.
. Sept. 7, 1886. Kniese. Carburetor to be used in the manufacture of ater gas.
. June 4, 1889. Paine. Oil burner.
). July 15, 1890. Hargreaves et al. Carburetor.
. Feb. 26, 1895. Cornish. Carburetor.
. Dec. 3, 1895. Bourgeois. Carburetor.
. Oct. 31, 1899. Kemp. Carburetor.
. July 31, 1900. Olds & Hough. Carburetor.
. Oct. 30, 1900. Lambert. Mixer and vaporizer for gas engines.
. Nov. 20, 1900. Rey. Carburetor.
. Nov. 27, 1900. Wünsche. Carburetor.
. Sept. 23, 1902. Rosenberry. Carburetor.
. Nov. 28, 1902. Tenney. Carburetor.
. Oct. 27, 1903. Chamberlain. Mixer for hydrocarbon engines.
0. Nov. 3, 1903. Smith. Carburetor for explosion engines.
8. Mar. 8, 1904. Weber. Carburetor.
8. Jan. 8, 1907. Parrott. Carburetor.
2. Feb. 12, 1907. Norton. Device for generating gas from crude oil.
0. May 7, 1907. Ellis. Automatic gasoline-gas machine.
1. Mar. 10, 1908. Meyers & Hickey. Apparatus for carbureting air.
0. Dec. 15, 1908. Schmitt & Neumann. Gas machine.
,951. Nov. 3, 1914. Martin. Carburetor.
,076. Dec. 1, 1914. Frey. Carburetor.
,128. Dec. 8, 1914. Browne. Carburetor.
,573. Dec. 8, 1914. Webber. Carburetor.
,540. July 11, 1916. Gettelman. Carburetor.
785. Oct. 22, 1867. Stuart. Improvement in carbureting gases.

Cross-reference patents, class 48, subclass 154.

83,748	189,645	247,390	405,747	646,780	760,247	1,116,825
148,579	199,781	251,673	427,197	673,542	852,685	
176,156	203,505	288,622	459,579	688,931	931,386	
176,395	206,402	288,868	564,429	712,803	957,731	

SUBCLASS 154.1, CARBURETORS, OIL FEED, SUCTION-CONTROLLED VALVE.

*423,214. Mar. 11, 1890. Butler. Hydrocarbon motor.
*498,447. May 30, 1893. Rolfson. Carburetor.
*500,401. June 27, 1893. Lehmann. Mixing valve for petroleum or other motors.
*509,828. Nov. 20, 1893. Rolfson. Carburetor.
*515,050. Feb. 20, 1894. Hoyt. Carbureting apparatus for gas or vapor engines.
*556,069. Mar. 10, 1896. Sintz. Carburetor.
*567,253. Sept. 8, 1896. Pratt. Vaporizer and mixer for gasoline engines.
*578,683. Mar. 9, 1897. Tregurtha. Vaporizer.
*609,557. Aug. 23, 1898. Phelps. Vaporizer for hydrocarbon oils.
*611,341. Sept. 27, 1898. Starr & Cogswell. Mixer and vaporizer for explosive engines.
*633,800. Sept. 26, 1899. Casgrain. Carburetor for explosive engines.
*649,191. May 8, 1900. Alderson. Carbureting and gas-mixing apparatus.
*670,921. Mar. 26, 1901. Olds. Carburetor.
*679,387. July 30, 1901. Mathieu. Carbureting apparatus for explosion motors.
*680,572. Aug. 13, 1901. Dyer. Vaporizer for explosive engines.
*680,961. Aug. 20, 1901. Buffum. Carburetor for explosive engines.
*688,367. Dec. 10, 1901. Tregurtha. Vaporizer for gasoline engines.
*690,112. Dec. 31, 1901. Kull. Carburetor or mixing valve for explosive engines.
*694,708. Mar. 4, 1902. White. Vaporizer for explosive engines.
*703,937. July 1, 1902. Lizotte. Vaporizer for explosive engines.
*705,995. July 29, 1902. Graves. Carburetor for explosive engines.
*714,982. Dec. 2, 1902. Widmayer et al. Generator or mixing valve.
*715,398. Dec. 9, 1902. Longuemare. Carburetor for explosive engines.
*717,000. Dec. 30, 1902. Henroid. Internal-combustion engine or motor.
*722,357. Mar. 10, 1903. Davis. Carburetor for gas engines.
*724,328. Mar. 31, 1903. Pivert. Mixing valve for explosion engines.
*727,476. May 5, 1903. Starr & Cogswell. Mixer for explosive gasoline engines.
*729,254. May 26, 1903. Bates. Carbureting device for explosive engines.
*730,608. June 9, 1903. Brush. Carbureting device for internal-combustion engines.
*731,218. June 16, 1903. Perkins. Vaporizer for internal-combustion engines.
*732,016. June 23, 1903. Uhlin. Explosive-engine governor.
*741,224. Oct. 13, 1903. Clark. Carburetor for explosive engines.
*741,959. Oct. 20, 1903. Emery. Vaporizer for hydrocarbon engines.
*746,833. Dec. 15, 1903. Hennegin. Fuel regulator for gasoline motors.
*747,235. Dec. 15, 1903. Saris. Carburetor for liquid-fuel engines.
*760,673. May 24, 1904. White & Duryea. Vaporizer for explosive engines.
*761,392. May 31, 1904. Olds. Carburetor for explosive engines.
*791,192. May 30, 1905. Haynes. Carburetor for explosion engines.
*806,079. Nov. 29, 1905. Gavelek. Carburetor for hydrocarbon engines.
*807,479. Dec. 19, 1905. Mason. Carburetor.
*816,477. Mar. 27, 1906. Kellog. Carburetor.
*820,408. May 15, 1906. Carlius. Vaporizing device for internal-combustion engines.
*826,531. July 24, 1906. Briest. Carburetor.
*826,787. July 24, 1906. Kemp. Carburetor.
*839,707. Dec. 25, 1906. Biehen. Carburetor.
*842,429. Jan. 29, 1907. Schuyler. Carburetor for explosion engines.
*848,425. Mar. 26, 1907. Anderson. Carburetor for gasoline engines.
*850,223. Apr. 17, 1907. Hallett. Carburetor.
*863,516. Aug. 13, 1907. Downing. Carburetor.
*866,490. Sept. 17, 1907. Lewis. Carburetor.
*871,730. Nov. 19, 1907. McHardy. Carburetor.

*876,210. Jan. 7, 1908. Miller. Carburetor.
*886,545. May 5, 1908. Schebler. Carburetor.
*888,263. May 19, 1908. Rader. Carburetor.
*890,099. June 9, 1908. Richardson. Carburetor.
*892,155. June 30, 1908. Hodges. Carburetor.
*896,388. Aug. 18, 1908. Johnston. Carburetor.
*903,206. Nov. 10, 1908. Lauson. Mixing valve.
*904,659. Nov. 24, 1908. Thompson. Carburetor.
*909,490. Jan. 12, 1909. Westaway. Carburetor.
*911,967. Feb. 9, 1909. Fox. Carburetor.
*912,998. Feb. 23, 1909. Eckert. Carburetor.
*912,999. Feb. 23, 1909. Eckert. Carburetor.
*913,313. Feb. 23, 1909. Slaughter. Carburetor for explosive motors.
*915,684. Mar. 16, 1909. Leinau. Carburetor.
*917,125. Apr. 6, 1909. Pierce. Carburetor.
*918,607. Apr. 20, 1909. Sturges. Carburetor.
*922,374. May 18, 1909. Wright. Mixer and vaporizer.
*926,848. July 6, 1909. Carlson. Carburetor.
*930,443. Aug. 10, 1909. Vaughan & McKensie. Carburetor.
*936,064. Oct. 5, 1909. Westaway. Carburetor.
*938,894. Nov. 2, 1909. Rapp. Carburetor.
*939,856. Nov. 9, 1909. Papanti. Carburetor.
*941,406 Nov 30, 1909. Cooper. Carburetor.
*944,811. Dec. 28, 1909. Nageborn. Internal-combustion engine.
*946,632. Jan. 18, 1910. Bassford. Carburetor.
*948,977. Feb. 8, 1910. Kingsbury. Carburetor.
*950,423. Feb. 22, 1910. Anderson & Mot. Carburetor.
*951,002. Mar. 1, 1910. Grott. Carburetor.
*952,326. Mar. 18, 1910. Hagar. Carburetor.
*955,222. Apr. 10, 1910. Stocker. Carburetor.
955,353. Apr. 19, 1910. Park. Carburetor.
*955,956. Apr. 26, 1910. Ennis. Carburetor.
*962,649. June 28, 1910. Miller. Carburetor.
*963,804. July 12, 1910. Peterson. Carburetor.
*964,409. July 12, 1910. Eckert. Carburetor.
*964,831. July 19, 1910. Wynn. Carburetor.
*966,381. Aug. 9, 1910. Brooke. Carburetor.
*971,038. Sept. 27, 1910. Gulick. Carburetor.
*971,862. Oct. 4, 1910. Schebler. Carburetor.
*973,882. Oct. 25, 1910. Rothe. Carburetor.
*974,083. Oct. 25, 1910. Daniel. Carburetor.
976,881. Nov. 29, 1910. Ivor. Carburetor.
*976,911. Nov. 29, 1910. Petersen & Pettit. Carburetor.
*978,076. Dec. 6, 1910. Tilden. Carburetor.
*978,787. Dec. 13, 1910. Smith. Carburetor.
*978,947. Dec. 20, 1910. Shaw. Carburetor.
*979,409. Dec 27, 1910. Barker. Carburetor.
*979,555. Dec. 27, 1910. Peterson. Carburetor.
*981,853. Jan. 17, 1911. Halladay. Carburetor.
*984,109. Feb. 14, 1911. Sailer. Carburetor.
*984,874. Feb. 21, 1911. Winton. Carburetor.
986,572. Mar. 14, 1911. Ivor. Carburetor.
*988,502. Apr. 4, 1911. Petre. Carburetor.
*988,659. Apr. 4, 1911. Phinney. Carburetor.
*993,096. May 23, 1911. Noyes. Gas and liquid mixer.
*993,210. May 23, 1911. Weiss. Carburetor.
*994,191. June 6, 1911. Peterson. Carburetor.
*994,195. June 6, 1911. Prescott. Carburetor.
*994,886. June 13, 1911. Swanberg. Generator valve for gasoline engine.
*995,623. June 20, 1911. Miller. Carburetor.
*997,417. July 11, 1911. Rothe. Carburetor.
*998,993. July 25, 1911. Skinner. Carbureting apparatus.
*999,038. July 25, 1911. Hubbard. Motive-fluid-supply valve.
*999,686. Aug. 1, 1911. Westaway. Carburetor.
*1,000,398. Aug. 15, 1911. Gentle. Carburetor.
*1,001,847. Aug. 29, 1911. Hobbs. Carburetor.
*1,003,101. Sept. 12, 1911. Gumz. Carburetor.

*1,004,091. Sept. 26, 1911. Shain. Carburetor for gas engines.
*1,007,659. Oct. 31, 1911. Rice. Carburetor.
*1,009,252. Nov. 21, 1911. Mallo. Carburetor.
*1,010,003. Nov. 28, 1911. Schulz. Carburetor.
*1,010,184. Nov. 28, 1911. Stewart. Carburetor.
*1,010,185. Nov. 28, 1911. Schulz. Carburetor.
*1,014,319. Jan. 9, 1912. Miller. Carburetor.
*1,014,682. Jan. 16, 1912. Weld. Carburetor.
*1,016,169. Jan. 30, 1912. Nagel. Carburetor.
1,019,800. Mar. 12, 1912. Kennedy. Carburetor.
*1,020,270. Mar. 12, 1912. Dunn. Carburetor.
*1,025,816. May 7, 1912. Lofthouse & Booty. Carburetor.
1,027,769. May 28, 1912. Roby. Carburetor.
*1,029,606. June 16, 1912. Guthrie. Valve mechanism for carburetors.
*1,029,897. June 18, 1912. Stewart. Carburetor.
*1,030,343. June 25, 1912. Stamps. Carburetor.
*1,032,307. July 9, 1912. Stewart. Carburetor.
*1,032,547. July 16, 1912. Howarth. Carburetor.
*1,033,130. July 23, 1912. Underwood & Hill. Carburetor.
*1,036,536. Aug. 27, 1912. Atkins. Carburetor or mixer for internal-combustion engines.
*1,040,528. Oct. 8, 1912. Dock. Carburetor.
*1,042,017. Oct. 28, 1912. Long. Carburetor.
*1,044,314. Nov. 12, 1912. Watson. Carburetor.
*1,046,111. Dec. 3, 1912. Schultz. Carburetor.
*1,046,141. Dec. 3, 1912. Becker. Gas-mixing valve for explosive engines.
*1,048,083. Dec. 24, 1912. Lavender. Carbureting device.
*1,048,954. Dec. 31, 1912. George. Carburetor.
*1,049,318. Dec. 31, 1912. Westaway. Carburetor.
*1,049,417. Jan. 7, 1913. Stewart. Carburetor.
*1,049,887. Jan. 7, 1913. Marsh. Carburetor.
*1,050,059. Jan. 7, 1913. Gould. Carburetor.
*1,051,440. Jan. 28, 1913. Ostler. Carburetor.
*1,059,501. Apr. 22, 1913. Stewart. Carburetor.
*1,060,545. Apr. 29, 1913. Gentle. Carburetor.
*1,061,582. May 13, 1913. Clement. Carburetor.
*1,063,030. May 27, 1913. Heidelmann. Carburetor.
*1,064,867. June 17, 1913. Stewart. Carburetor.
*1,066,080. July 1, 1913. Cole. Carburetor.
*1,067,351. July 15, 1913. Lavigne. Carburetor.
*1,067,623. July 15, 1913. Schulz. Carburetor.
*1,069,389. Aug. 5, 1913. Conklin. Carburetor.
*1,071,003. Aug. 19, 1913. Drayton & Woodroffe. Carburetor.
1,074,575. Sept. 30, 1913. Riotte. Carburetor.
*1,077,256. Nov. 4, 1913. Brush. Carburetor.
*1,078,413. Nov. 11, 1913. Cahill. Carburetor.
*1,078,590. Nov. 11, 1913. Muir. Carburetor.
*1,078,591. Nov. 11, 1913. Muir. Carburetor.
*1,078,592. Nov. 11, 1913. Muir. Carburetor.
*1,079,947. Dec. 2, 1913. Morris. Carburetor.
*1,080,696. Dec. 9, 1913. Hugelet. Carburetor.
*1,081,222. Dec. 9, 1913. Dürr. Carburetor.
*1,084,693. Jan. 20, 1914. Cahill. Carburetor.
*1,084,954. Jan. 20, 1914. Nice. Carburetor.
*1,085,194. Jan. 27, 1914. Russian & Noble. Carburetor.
*1,086,359. Feb. 10, 1914. Faries. Carburetor for gas and gasoline engines.
*1,087,187. Feb. 17, 1914. Schultz. Carburetor.
*1,087,218. Feb. 17, 1914. Dalton & Conklin. Carburetor.
1,089,231. Feb. 24, 1914. Lawrence. Carburetor for internal-combustion engines.
*1,092,079. Mar. 31, 1914. Reeder. Carburetor.
*1,095,402. May 5, 1914. Jordan. Carburetor.
*1,097,787. May 26, 1914. Brewer & Jones. Carburetor.
*1,103,864. July 14, 1914. Brown. Carburetor.
*1,104,494. July 21, 1914. Hamill. Carburetor.
*1,111,179. Sept. 22, 1914. Pratt. Carburetor.
*1,112,641. Oct. 6, 1914. Moeller. Fluid mixing and regulating device.
*1,114,222. Oct. 20, 1914. Brigham. Carburetor.

*1,115,951. Nov. 3, 1914. Martin. Carburetor.
*1,120,128. Dec. 8, 1914. Browne. Carburetor.
*1,120,397. Dec. 8, 1914. Martin. Carburetor.
*1,120,573. Dec. 8, 1914. Webber. Carburetor.
*1,123,048. Dec. 29, 1914. Washburn. Carburetor.
*1,124,911. Jan. 12, 1915. Johnston. Valve for gas engine.
*1,125,525. Jan. 19, 1915. Rathcock. Carburetor.
*1,126,159. Jan. 26, 1915. Dressel. Floatless carburetor.
*1,126,249. Jan. 26, 1915. Mitchell. Carburetor.
*1,126,690. Jan., 1915. Beucus. Carburetor.
*1,130,228. Mar. 2, 1915. Whiting. Vaporizer for internal-combustion engines.
*1,132,934. Mar. 23, 1915. Heitger. Carburetor.
*1,135,270. Apr. 13, 1915. Duryea. Carburetor.
*1,135,689. Apr. 13, 1915. Harroun. Carburetor.
*1,137,727. May 4, 1915. Abernethy. Carburetor for internal-combustion engines.
*1,137,728. May 4, 1915. Abernethy. Carburetor for vaporizer for explosive engines.
*1,138,204. May 4, 1915. Folberth. Carburetor.
*1,139,914. May 18, 1915. Smilie. Carburetor.
*1,140,525. May 25, 1915, Motsinger. Proportioning device especially designed for carburetors.
*1,141,085. May 25, 1915. Kent. Carburetor.
*1,145,172. July 6, 1915. Speed. Carburetor.
*1,145,854. July 6, 1915. Winkley & Hart. Carburetor for hydrocarbon motors.
*1,145,871. July 6, 1915. Smith. Carburetor.
*1,146,181. July 13, 1915. Lippold. Carburetor.
*1,147,672. July 20, 1915. Bell. Carburetor.
*1,149,908. Aug. 10, 1915. Goudard & Mennesson. Carburetor.
*1,156,828. Oct. 12, 1915. Schebler. Carburetor.
*1,158,324. Oct. 26, 1915. Smith. Carburetor.
*1,158,359. Oct. 26, 1915. Abell. Carburetor.
*1,159,005. Nov. 2, 1915. Funderburk. Carburetor.
*1,159,029. Nov. 2, 1915. Hodges. Carburetor.
*1,159,049. Nov. 2, 1915. Kirby. Carburetor.
*1,161,374. Nov. 23, 1915. Bjorklund. Carburetor.
*1,165,359. Dec. 21, 1915. Motsinger. Carburetor.
*1,167,426. Jan. 11, 1916. Park. Carburetor.
*1,168,782. Jan. 18, 1916. Bucker. Carburetor.
*1,169,574. Jan. 25, 1916. Schultz. Carburetor.
*1,171,679. Feb. 15, 1916. Veliguth. Carburetor.
*1,171,716. Feb. 15, 1916. Haas. Carburetor.
*1,172,258. Feb. 22, 1916. Coulombe. Carbureting mechanism for gas engines.
*1,172,595. Feb. 22, 1916. Heath & Taylor. Carburetor.
*1,178,064. Apr. 4, 1916. Fahrney. Carburetor.
*1,178,473. Apr. 4, 1916. Sunderman. Carburetor.
*1,178,866. Apr. 11, 1916. Meier. Carburetor.
*1,179,568. Apr. 18, 1916. Schortt. Carburetor.
*1,179,913. Apr. 18, 1916. Hamill. Carburetor.
*1,181,356. May 2, 1916. Tjompson & Arkenberg. Carburetor.
*1,183,538. May 16, 1916. Collett. Carburetor.
*1,184,696. May 23, 1916. Costa. Carburetor.
*1,192,106. July 15, 1916. Pembroke. Carburetor.
1,187,996. June 20, 1916. Kapp. Carburetor.
*Re. 13,908 (orig. 783,902). Apr. 20, 1915. Shipman. Carburetor.

Cross-reference patents, class 48, subclass 154.1.

938,894	1,022,326	1,065,503	1,116,673	1,130,950	1,147,887	1,166,178
975,696	1,023,470	1,074,575	1,119,076	1,131,157	1,148,247	1,167,217
976,237	1,038,050	1,082,007	1,119,078	1,133,904	1,155,407	1,168,788
976,409	1,042,004	1,086,226	1,130,350	1,138,829	1,156,836	1,173,762
995,919	1,052,051	1,101,736	1,130,474	1,140,000	1,162,680	Re. 13,580
1,020,198	1,061,995	1,108,245	1,130,502	1,143,779	1,164,661	

SUBCLASS 155, CARBURETORS, ATOMIZERS.

49,934. Sept. 2, 1865. Terry. Improved apparatus for carbureting air.
53,481. Mar. 27, 1866. Pond & Richardson. Improved apparatus for carbureting air.
63,326. Mar. 26, 1867. Stephenson. Improved apparatus for carbureting gas and air.
66,009. June 25, 1867. Bassett. Carburetor.
146,458. Jan. 13, 1874. Jüngling. Improvement in carburetor.
146,493. Jan. 13, 1874. Vasquez. Improvement in carburetors.
228,547. June 8, 1880. Maxim. Gas apparatus.
238,757. Mar. 15, 1881. Brainard. Carburetor.
272,848. Feb. 27, 1883. Billings. Apparatus for manufacturing gas.
320,460. June 23, 1885. Copeland. Carburetor.
367,936. Aug. 9, 1887. Shaw. Hydrocarbon and gas-impulse feeder for gas engines.
423,898. Mar. 25, 1890. Bradley. Air carburetor.
464,779. Dec. 8, 1891. Reichholm & Machlet. Apparatus for and method of making fuel gas.
483,003. Sept. 20, 1892. Mendenhall. Apparatus for carbureting air.
485,877. Nov. 8, 1892. Noteman. Apparatus for making gas.
498,673. May 30, 1893. Mulvey. Apparatus for carbureting air.
509,174. Nov. 21, 1893. Lawrence. Apparatus for carbureting gas.
576,108. Feb. 2, 1897. Gibson. Carburetor.
*581,930. May 4, 1897. Alderson. Gas mixer.
*593,911. Nov. 16, 1897. Snow. Vaporizing carburetor and air governor for gas engine.
652,631. June 26, 1900. Pender. Carburetor.
*654,894. July 31, 1900. Hasbrouch. Regulator for gasoline or other like engines.
*657,740. Sept. 11, 1900. Kiltz. Carburetor for gas engines.
*666,623. Jan. 22, 1901. Gebhart. Hydrocarbon vaporizer and mixer for explosion engines.
677,852. July 9, 1901. Brown & Donnelly. Carburetor.
678,194. July 9, 1901. Pickles. Carburetor.
702,378. June 10, 1902. Roemisch & Orre. Carburetor.
*705,314. July 22, 1902. Blake. Carburetor.
*706,050. Aug. 5, 1902. Hardy. Mixing valve for gas or gasoline engines.
713,983. Nov. 18, 1902. Heath. Carburetor for explosive engines.
*721,238. Feb. 24, 1903. Rousseau. Vapor feeder and throttle for gas engines.
*725,741. Apr. 21, 1903. Miller. Fuel-feed regulator for explosive engines.
*726,191. Apr. 21, 1903. Readie. Vaporizing valve for explosive engines.
736,157. Aug. 11, 1903. Sams. Atomizing and carbureting device.
758,789. May 3, 1904. Slining carburetor.
*761,192. May 31, 1904. Bean. Mixing and vaporizing device for motors.
*770,559. Sept. 20, 1904. Clay. Carburetor for explosive engines.
*793,498. June 27, 1905. Ash. Carburetor for hydrocarbon engines.
797,615. Aug. 22, 1905. Schmitt. Carburetor.
*807,144. Dec. 12, 1905. Walker. Carburetor.
*817,721. Apr. 10, 1906. Lewis. Carburetor.
*827,094. July 31, 1906. Grant. Carburetor.
828,274. Aug. 7, 1906. Cornish. Carburetor.
828,940. Aug. 21, 1906. Lanard. Carburetor.
*836,764. Nov. 27, 1906. Heath. Carburetor.
846,395. Mar. 5, 1907. Busenbenz. Gas-manufacturing apparatus.
*856,638. June 11, 1907. Higgins. Carburetor.
857,130. June 18, 1907. Way. Carburetor.
861,758. July 30, 1907. McCanna. Carburetor.
864,037. Aug. 20, 1907. Selley. Carburetor.
*867,604. Oct. 8, 1907. Rothe. Carburetor.
878,297. Feb. 4, 1908. Levavasseur. Carburetor.
*878,824. Feb. 11, 1908. Newbrough. Carburetor for explosive engines.
885,230. Apr. 21, 1908. Von Dulong. Apparatus for the production of gases from hydrocarbon.
890,970. June 16, 1908. Dörr. Carbureting apparatus for explosive engines.
896,422. Aug. 18, 1908. Sylva. Carbureting and oil-separating apparatus.
*905,012. Nov. 24, 1908. Spranger. Carburetor.

907,123. Dec. 22, 1908. Broderick. Carburetor.
*939,481. Nov. 9, 1909. Dickson. Carburetor.
940,652. Nov. 16, 1909. Nye. Carburetor.
*962,140. June 21, 1910. Hall & Dicks. Carburetor.
*968,215. Aug. 23, 1910. Westaway. Carburetor.
*973,937. Oct. 25, 1910. Haines. Carburetor.
*974,076. Oct. 25, 1910. Kingston. Carburetor.
985,500. Feb. 28, 1911. Baujard. Carburetor.
*1,041,662. Oct. 15, 1912. Noyes. Vacuum fuel feeder and carburetor.
*1,081,900. Dec. 16, 1913. Fagerberg. Engine primer.
,104,222. July 21, 1914. Rimmer et al. Carburetor.
118,897. Nov. 24, 1914. Dougherty. Means for carbureting air.
,127,120. Feb. 2, 1915. Veeder. Carburetor.
141,258. June 1, 1915. Noyes. Liquid feeder for burners, etc.
155,232. Sept. 28, 1915. Hagar. Carburetor.
55,829. Oct. 5, 1915. McAdam. Carburetor.
63,749. Dec. 14, 1915. Gallagher. Carburetor.
84,873. May 30, 1916. Raymond. Carburetor.
7,826. June 20, 1916. France. Carburetor nozzle.
8,754. June 27, 1916. Geer et al. Fuel-oil atomizer.
13,111 (orig. 886,688). May 3, 1910. Higgins. Carburetor.

Cross-reference patents, class 48, subclass. 155.

132,025	696,231	773,543	848,963	961,481	995,623	1,106,192
212,502	746,119	778,988	871,480	976,781	1,001,847	1,116,825
623,321	750,764	793,776	881,431	977,813	1,037,833	1,141,258
643,306	762,707	846,680	921,934	979,908	1,074,625	1,157,146

SUBCLASS 155.1, CARBURETORS, ATOMIZERS, CONSTANT LEVEL.

,242. Oct. 3, 1899. Lambert. Mixing device for gasoline engines.
,166. Oct. 17, 1899. Hay. Vaporizer for gas engines.
,566. Mar. 6, 1900. Aslakson. Internal-combustion engine.
,324. May 8, 1900. Longuemare. Carburetor for explosive engines.
,382. Aug. 27, 1901. Westman. Feed cup for explosive engines.
,596. Sept. 17, 1901. Aldrich. Carbureting device for explosive engines.
,989. Jan. 14, 1902. Olds. Liquid-fuel feed for explosive engines.
,773. Feb. 18, 1902. Bardwell. Carburetor for explosive engines.
555. Apr. 15, 1902. Settergren. Mixer or vaporizer for hydrocarbon engines.
,309. May 6, 1902. Hamilton. Carbureting device for internal-combustion motors.
,504. May 6, 1902. Duryea. Carburetor for explosive engines.
,469. June 17, 1902. Parkin. Carburetor for explosive engines.
,005. Oct. 14, 1902. Schebler. Carburetor.
,597. Nov. 25, 1902. Mors. Carburetor for explosive motors.
,486. Feb. 3, 1903. Messinger. Carburetor for internal-combustion engines.
,536. Feb. 3, 1903. Tuttle. Vaporizer or carburetor for explosive engines.
,648. Apr. 7, 1903. Zimmerman. Vaporizer for gas engines.
,972. May 12, 1903. Kingston. Carburetor for gasoline engines.
9,467. May 26, 1903. White. Explosion engine.
0,649. June 9, 1903. Hedstrom. Carburetor for explosive engines.
4,848. July 28, 1903. Gill. Carburetor for explosive engines.
7,463. Aug. 25, 1903. Pearson. Vaporizer for explosive engines.
41,962. Oct. 20, 1903. Grouvelle & Arquembourg. Regulator for carburetors for explosive engines.
745,063. Nov. 24, 1903. Jenness. Carburetor for gasoline engines.
*746,449. Dec. 8, 1903. Brennan. Carburetor for gas engines.
*756,908. Apr. 12, 1904. Swain. Carburetor for gas engines.
*759,001. May 3, 1904. Mohler. Carburetor for hydrocarbon engines.
*759,396. May 10, 1904. Rutenber. Carburetor for hydrocarbon engines.
*767,716. Aug. 16, 1904. Ritchie. Carburetor.
*771,096. Sept. 27, 1904. Richard. Carburetor for explosion engines.
*771,985. Oct. 11, 1904. Kingston. Carburetor for gasoline engines.

*772,979. Oct. 25, 1904. Vaurs. Carburetor for hydrocarbon engines.
*775,553. Nov. 22, 1904. Burton & Seibel. Carburetor for hydrocarbon engines.
*776,406. Nov. 29, 1904. Lamb. Vaporizer for hydrocarbon engines.
*780,949. Jan. 24, 1905. Huber. Carburetor for hydrocarbon engines.
*789,537. May 9, 1905. Grouvelle & Arquembourg. Atomizing carburetor for explosive engines.
*789,749. May 16, 1905. Maxwell. Carburetor for gas engines.
*791,801. June 6, 1905. Leinau. Carburetor for hydrocarbon engines.
*791,810. June 6, 1905. Orr. Carburetor.
*794,502. July 11, 1905. Hennebutte. Carburetor.
*794,927. July 18, 1905. Cushman. Carburetor.
*794,951. July 18, 1905. Shaaf & Lacy. Carburetor.
*795,357. July 25, 1905. Maxwell. Carburetor.
*797,972. Aug. 22, 1905. Moreland. Vaporizer for explosive engines.
*802,038. Oct. 17, 1905. Hagar. Carburetor for hydrocarbon engines.
*804,025. Nov. 7, 1905. Minton. Carburetor for gas engines.
*813,683. Feb. 27, 1906. Adams. Carburetor.
*815,712. Mar. 20, 1906. Johnston. Carburetor for explosive engines.
*816,846. Apr. 3, 1906. Charron & Girardot. Carburetor for petroleum motors.
*817,641. Apr. 10, 1906. Harris. Carburetor.
*817,903. Apr. 17, 1906. Comstock. Carburetor.
*821,081. May 22, 1906. Brennan. Carburetor.
*823,608. June 19, 1906. Malezieux. Carburetor for explosive engines.
*825,499. July 10, 1906. Sturtevant. Carburetor for gas engines.
*825,754. July 10, 1906. Pearson. Vaporizer for hydrocarbon engines.
*826,531. July 24, 1906. Briest. Carburetor.
*828,228. Aug. 7, 1906. Menns. Carburetor.
*829,345. Aug. 21, 1906. Menns. Carburetor.
*842,052. Jan. 22, 1907. Anderson. Carburetor.
*846,903. Mar. 12, 1907. Bradbeer. Carburetor.
*851,285. Apr. 23, 1907. Freeman. Carburetor for an explosive engine.
*853,428. May 14, 1907. Trebert. Carburetor.
*854,246. May 21, 1907. Smith. Carburetor.
*855,179. May 28, 1907. Jenness. Carburetor.
*859,719. July 9, 1907. Anderson. Carburetor.
*862,083. July 30, 1907. Longennecker. Carburetor.
*863,739. Aug. 20, 1907. Maxwell. Carburetor.
*864,111. Aug. 20, 1907. Sickles. Carburetor.
*865,522. Sept. 10, 1907. Park. Carburetor.
*873,392. Dec. 10, 1907. Stoker. Carburetor.
*876,800. Jan. 14, 1908. Gundelach. Carburetor.
*878,770. Feb. 11, 1908. Cahill. Carburetor.
*881,279. Mar. 10, 1908. Allen. Carburetor for internal-combustion engines.
*883,740. Apr. 7, 1908. Poppe. Spray carburetor.
*886,526. May 5, 1908. Marr. Carburetor.
*886,527. May 5, 1908. Marr. Carburetor.
*889,487. June 2, 1908. Schneble. Carburetor for internal-combustion engines.
*889,558. June 2, 1908. Thomas. Carburetor.
*890,273. June 9, 1908. Maak & Munzert. Carburetor.
*893,685. July 31, 1908. Willard. Carburetor.
*898,361. Sept. 8, 1908. Heitger. Carburetor.
*900,098. Oct. 6, 1908. Heitger. Carburetor.
*907,279. Dec. 22, 1908. Perry. Carburetor
*907,881. Dec. 29, 1908. Reineking. Carburetor.
*908,764. Jan. 5, 1909. Fosnot. Carburetor for explosive engines.
*910,326. Jan. 19, 1909. Stevenson. Carburetor.
*911,153. Feb. 2, 1909. Otis. Carburetor.
*911,349. Feb. 2, 1909. Weiland. Carburetor.
*913,354. Feb. 23, 1909. Breese. Carburetor.
*915,647. Mar. 16, 1909. Young. Carburetor.
*920,231. May 4, 1909. White. Carburetor for internal-combustion engines.
*924,673. June 15, 1909. Knickerboxer. Carburetor.
*926,039. June 22, 1909. Warren. Carburetor.
*928,828. July 20, 1909. Winton. Carburetor.
*930,724. Aug. 10, 1909. Boore. Carburetor.

32,360. Aug. 24, 1909. Watt. Carburetor.
35,833. Oct. 5, 1909. Bassford. Carburetor.
36,118. Oct. 5, 1909. Glover. Carburetor.
36,337. Oct. 12, 1909. Maybach. Carburetor.
37,536. Oct. 19, 1909. Knight. Carburetor.
15,167. Jan. 10, 1910. Holley. Carburetor.
17,712. Jan. 25, 1910. Hendricks. Carburetor.
50,278. Feb. 22, 1910. Basey. Carburetor.
54,488. Apr. 12, 1910. Wolf. Carburetor.
54,630. Apr. 12, 1910. Howarth. Carburetor.
55,292. Apr. 10, 1910. Sickles. Carburetor.
57,976. May 17, 1910. Lucas. Atomizer and the like.
58,128. May 17, 1910. Howarth. Carburetor.
58,897. May 24, 1910. Snedeker. Carburetor.
60,601. June 7, 1910. Stewart. Carburetor.
60,697. June 7, 1910. Plein. Carburetor.
63,187. July 5, 1910. Tuerk. Carburetor.
67,407. Aug. 16, 1910. Mayer. Carburetor for explosive engines.
73,855. Oct. 25, 1910. Cannon. Carburetor.
76,322. Nov. 22, 1910. Walters. Carburetor.
76,344. Nov. 22, 1910. Christofferson et al. Carburetor.
76,409. Nov. 22, 1910. Stickler. Vaporizer or carburetor.
76,692. Nov. 22, 1910. Reichenbach. Carburetor.
76,813. Nov. 22, 1910. Kreis. Carburetor.
77,831. Dec. 6, 1910. Page. Carburetor.
80,668. Jan. 3, 1911. Paull. Carburetor.
83,247. Jan. 31, 1911. Miller. Carburetor.
83,541. Feb. 7, 1911. Dawson. Carburetor.
83,836. Feb. 7, 1911. Plein. Carburetor.
85,431. Feb. 28, 1911. McHardy & Potter. Carburetor.
85,999. Mar. 7, 1911. Harris. Carburetor.
88,638. Apr. 4, 1911. Harris. Carburetor.
88,800. Apr. 4, 1911. McHardy & Potter. Carburetor.
93,065. May 23, 1911. Herschberger. Carburetor.
93,097. May 23, 1911. Noyes. Anterior-throttles carburetor.
98,457. July 18, 1911. Bingham. Carburetor.
1,000,451. Aug. 15, 1911. Stevenson. Carburetor.
1,000,518. Aug. 15, 1911. Harris. Carburetor.
002,458. Sept. 5, 1911. Sekowsky. Carburetor.
1,002,646. Sept. 5, 1911. Conrad. Carburetor.
1,005,491. Oct. 10, 1911. Wiland. Carburetor.
1,006,088. Oct. 17, 1911. Hippisley. Carburetor.
1,007,729. Nov. 7, 1911. Poppe. Carburetor for internal-combustion engines.
1,011,565. Dec. 12, 1911. Brock. Carburetor.
1,012,781. Dec. 26, 1911. Winters. Carburetor.
1,013,708. Jan. 2, 1912. Weiland. Carburetor.
,014,188. Jan. 9, 1912. Voorhees. Carburetor.
,016,251. Feb. 6, 1912. Dayton. Carburetor.
017,186. Feb. 13, 1912. Stewart. Carburetor.
,019,209. Mar. 5, 1912. Welsh. Carburetor.
020,198. Mar. 12, 1912. Hamill. Carburetor for internal-combustion engines.
020,931. Mar. 19, 1912. Smith. Carburetor.
023,470. Apr. 16, 1912. Hill & Underwood. Carburetor.
026,491. May 14, 1912. Browning. Carburetor.
027,459. May 28, 1912. Barnard. Carburetor.
028,723. June 4, 1912. Hezinger. Carburetor.
029,796. June 18, 1912. Dawson. Apparatus for producing an explosive or combustible mixture of liquid fuel and air.
031,147. July 2, 1912. Plumm. Spray carburetor.
033,886. July 30, 1912. Gentle. Carburetor.
036,301. Aug. 20, 1912. Miller. Carburetor.
,037,833. Sept. 3, 1912. Noyes. Automatic regulation for carburetors.
,037,834. Sept. 3, 1912. Raymond. Carburetor.
,038,804. Sept. 12, 1912. Warren. Carburetor.
,038,921. Sept. 17, 1912. Martin. Carburetor.
,042,077. Oct. 22, 1912. Brown. Carburetor.

*1,042,606. Oct. 29, 1912. Roth. Carburetor.
*1,042,528. Oct. 29, 1912. Brown. Carburetor.
*1,043,077. Nov. 5, 1912. Dock. Carburetor.
*1,044,754. Nov. 19, 1912. Coulter. Carburetor.
*1,045,251. Nov. 26, 1912. Bourne. Carburetor.
*1,045,613. Nov. 26, 1912. Roth. Carburetor.
*1,049,038. Dec. 31, 1912. Barstow & Bradford. Carburetor for internal-combustion engines.
*1,052,051. Feb. 4, 1913. Grimes. Carburetor.
*1,052,397. Feb. 4, 1913. Wingfield. Carburetor for petrol motors.
*1,053,136. Feb. 11, 1913. Daellenbach. Carburetor.
*1,055,042. Mar. 4, 1913. Higgins. Carburetor.
*1,057,506. Apr. 1, 1913. Stevens. Carburetor for internal-combustion engines.
*1,061,995. May 20, 1913. Erickson. Carburetor.
*1,064,627. June 10, 1913. Ensign. Vaporizer.
*1,064,628. June 10, 1913. Ensign. Carburetor.
1,064,866. June 17, 1913. Stewart. Throttle for carburetors.
*1,065,067. June 17, 1913. Naczek. Carburetor.
*1,065,462. June 24, 1913. Miller. Carburetor.
*1,065,503. June 24, 1913. Byrom. Carburetor.
*1,066,608. July 8, 1913. Harris. Carburetor.
*1,067,449. July 15, 1913. Steward. Carburetor.
*1,072,376. Sept. 2, 1913. Alden. Carburetor.
*1,072,492. Sept. 9, 1913. Pierson. Carburetor.
*1,072,565. Sept. 9, 1913. Bräutigam. Carburetor.
*1,074,625. Oct. 7, 1913. Johnson et al. Carburetor.
*1,081,203. Dec. 9, 1913. Bull. Carburetor.
1,081,258. Dec. 9, 1913. Ulrich & Rahr. Carburetor.
*1,082,466. Dec. 23, 1913. Lucas. Carburetor for internal-combustion engines.
*1,085,003. Jan. 20, 1914. Austin. Carburetor.
*1,086,226. Feb. 3, 1914. Sassano. Carburetor.
*1,086,594. Feb. 10, 1914. Goldberg. Carburetor.
*1,088,181. Feb. 24, 1914. Raymond. Carburetor.
*1,088,664. Feb. 24, 1914. Lamb. Vaporizer for internal-combustion engines.
*1,088,974, Mar. 3, 1914. Drysdale. Carburetor.
*1,090,209. Mar. 17, 1914. Heitger. Carburetor.
*1,091,426. Mar. 24, 1914. Davis. Carburetor.
*1,092,953. Apr. 14, 1914. Sanborn. Carburetor.
*1,095,101. Apr. 28, 1914. Gardner. Carburetor.
*1,095,510. May 5, 1914. Miller. Carburetor.
*1,096,482. May 12, 1914. Winton. Carburetor.
*1,096,626. May 12, 1914. Heftler. Carburetor.
*1,097,165. May 19, 1914. Bucherer. Spray carburetor.
*1,097,401. May 19, 1914. Donndorf. Jet carburetor.
*1,101,736. June 30, 1914. Gillet. Carburetor.
*1,103,178. July 14, 1914. Eiker. Carburetor.
*1,103,802. July 14, 1914. Meissner. Carburetor.
*1,103,864. July 14, 1914. Howarth. Carburetor.
*1,105,200. July 28, 1914. Brown. Carburetor.
*1,106,258. Aug. 4, 1914. Tucker & Wilding. Carburetor.
*1,107,698. Aug. 18, 1914. Norton. Carburetor.
*1,107,713. Aug. 18, 1914. Shakespeare & Schmidt. Carburetor.
*1,108,727. Aug. 25, 1914. Ensign. Vaporizer.
*1,111,763. Sept. 29, 1914. Rogers. Carburetor.
*1,113,221. Oct. 13, 1914. Krause. Carburetor.
*1,113,533. Oct. 13, 1914. Barrett. Carburetor.
*1,116,023. Nov. 3, 1914. Crawford. Carburetor.
*1,116,581. Nov. 10, 1914. Foulds. Carburetor.
*1,116,986. Nov. 10, 1914. Bull. Carburetor for internal-combustion engines.
*1,118,459. Nov. 24, 1914. Winkler. Self-leveling carburetor.
*1,118,917. Dec. 1, 1914. Bucker. Carburetor.
*1,118,919. Dec. 1, 1914. Canda. Carburetor.
*1,119,181. Dec. 1, 1914. Leduc. Carburetor.
*1,119,821. Dec. 8, 1914. Gilliland & Sharpneck. Carburetor.
*1,120,763. Dec. 15, 1914. Thomas. Carburetor.
*1,120,845. Dec. 15, 1914. Parkin. Carburetor.
*1,121,630. Dec. 22, 1914. Holley. Carburetor.

*1,123,027. Dec. 29, 1914. Simonson. Carburetor.
*1,123,955. Jan. 5, 1915. Tice. Carburetor.
*1,124,949. Jan. 12, 1915. Raymond. Carburetor.
*1,125,338. Jan. 19, 1915. Keizer. Carburetor.
*1,125,339. Jan. 19, 1915. Keizer. Carburetor.
*1,125,340. Jan. 19, 1915. Keizer. Carburetor.
*1,126,127. Jan. 26, 1915. Swan. Carburetor.
1,127,286. Feb. 2, 1915. Russell. Carburetor.
*1,129,103. Feb. 23, 1915. Keller. Carburetor for explosive engines.
*1,129,129. Feb. 23, 1915. Shakespeare & Schmidt. Carburetor.
*1,130,981. Mar. 9, 1915. Kingston. Carburetor.
*1,131,312. Mar. 9, 1915. Beamer & Duffy. Carburetor.
*1,132,314. Mar. 16, 1915. Eiker. Carburetor.
*1,133,754. Mar. 30, 1915. Shortt. Carburetor.
*1,134,021. Mar. 30, 1915. Sohon. Carburetor.
*1,134,365. Apr. 6, 1915. Barnes. Carburetor.
*1,135,046. Apr. 13, 1915. Ottaway. Carburetor.
*1,135,315. Apr. 13, 1915. Odell. Carburetor.
*1,135,544. Apr. 13, 1915. Norton. Carburetor.
*1,135,729. Apr. 13, 1915. Schoof. Carburetor.
*1,137,238. Apr. 27, 1915. Sherman. Carburetor.
*1,137,307. Apr. 27, 1915. Edens. Carburetor.
*1,139,851. May 18, 1915. Dayton. Carburetor.
*1,140,071. May 18, 1915. Rothe. Carburetor.
*1,140,232. May 18, 1915. Allen. Carburetor.
*1,140,721. May 25, 1915. Stamps. Carburetor.
*1,140,722. May 25, 1915. Stamps. Carburetor.
*1,142,768. June 8, 1915. Perry. Carburetor.
*1,143,227. June 15, 1915. Prescott. Carburetor.
*1,143,511. June 15, 1915. Cox. Carburetor.
*1,148,333. July 27, 1915. Payne. Carburetor.
*1,148,898. Aug. 3, 1915. Henley. Carburetor.
*1,149,035. Aug. 3, 1915. Doué. Carburetor.
*1,149,743. Aug. 10, 1915. England. Thermostatic control for the valve of a carburetor.
*1,150,782. Aug. 17, 1915. Lucas. Carburetor for internal-combustion engines.
*1,151,159. Aug. 24, 1915. Brown. Carburetor.
*1,151,286. Aug. 24, 1915. Rowell. Carburetor.
*1,153,891. Sept. 21, 1915. Breath. Carburetor.
*1,151,578. Aug. 31, 1915. Entz. Carburetor.
*1,153,999. Sept. 21, 1915. Carpenter. Carburetor.
*1,157,363. Oct. 19, 1915. Blomquist. Carburetor.
*1,157,507. Oct. 19, 1915. Cerný. Carburetor.
*1,157,541. Oct. 19, 1915. Huskisson. Carburetor.
*1,160,662. Nov. 16, 1915. Slaby. Carburetor.
*1,161,437. Nov. 23, 1915. Beamer & Duffy. Carburetor.
*1,162,111. Nov. 30, 1915. Simpson. Carburetor.
*1,162,576. Nov. 30, 1915. Daimler & Slaby. Throttle valve for carburetors.
*1,163,581. Dec. 7, 1915. Alley. Carburetor.
*1,163,749. Dec. 14, 1915. Gl. Gallagher. Carburetor.
*1,165,087. Dec. 21, 1915. Fulton. Carburetor.
*1,165,224. Dec. 21, 1915. Cadett. Carburetor.
*1,169,483. Jan. 25, 1916. Henley. Carburetor.
*1,171,235. Feb. 8, 1916. Olsen. Carburetor.
*1,173,378. Feb. 29, 1916. Payton. Carburetor.
*1,173,762. Feb. 29, 1916. Arquembourg. Carburetor.
*1,174,529. Mar. 7, 1916. Sykes. Carburetor.
*1,177,395. Mar. 28, 1916. Dickie. Carburetor.
*1,178,127. Apr. 4, 1916. Bricken. Carburetor.
*1,178,296. Apr. 4, 1916. Cahill. Carburetor.
*1,179,663. Apr. 18, 1916. Shakespeare & Schmid. Carburetor.
*1,180,939. Apr. 25, 1916. Ostenberg. Carburetor.
*1,181,514. May 2, 1916. Eynon. Carburetor.
*1,183,125. May 16, 1916. Shakespeare & Schmid. Carburetor.
*1,184,541. May 23, 1916. Kustel. Carburetor.
*1,184,873. May 30, 1916. Raymond. Carburetor.
*1,184,888. May 30, 1916. Stevens. Carburetor.

*1,184,889. May 30, 1916. Stevens. Carburetor.
*1,185,574. May 30, 1916. Allen. Carburetor.
1,186,976. June 13, 1916. Dugrey. Carburetor.
1,186,588. June 13, 1916. Lemon. Carburetor.
1,187,945. June 20, 1916. Briggle. Carburetor.
*1,190,715. July 11, 1916. Bottome. Carburetor.
*1,192,213. July 25, 1916. Lamb. Carburetor.

Cross-reference patents, class 48, subclass 155.1.

62,856	741,810	807,479	907,123	954,905	964,657	968,215
726,986	747,235	862.574	909,490	959,066	966,881	971,862
733,625	760,673	891,322	915,684			
973,877	1,005,300	1,038,699	1,073,473	1,120,128	1,151,989	1,166,734
978,076	1,006,411	1,040,414	1,078,582	1,124,697	1,152,173	1.167,457
979,700	1,007,659	1,040,619	1,084,028	1,131,371	1,153,436	1,169,340
984,032	1,008,155	1,041,099	1,089,089	1,134,366	1,153,487	1,169,592
984,109	1,011,960	1,043,342	1,097,039	1,141,570	1,155,457	1,170,416
985,670	1,018.164	1,046,141	1,099,086	1,144,206	1,157,116	1,171,074
986,572	1,018,776	1,048,518	1,105,003	1,145,476	1,159,423	1,176,267
995,976	1,029,897	1,062,688	1,106,226	1,148,485	1,163,223	
1,001,950	1,033,443	1,065,948	1,106,935	1,149,908	1,165,914	
1,001,969	1,038,262	1,073,179	1,110,453	1,150,115	1,166,595	

SUBCLASS 155.2, CARBURETORS, ATOMIZERS, CONSTANT LEVEL, AUTOMATIC DILUTION.

*656,197. Aug. 21, 1900. Lumière. Carburetor for petroleum or other engines.
*654,841. Jan. 1, 1901. Duryea. Mixer for explosive engines.
*667,910. Feb. 12, 1901. Hatcher & Packard. Mixer and vaporizer for explosive engines.
*713,146. Nov. 11, 1902. Power. Vaporizing carburetor.
*744,257. Nov. 17, 1903. Sturtevant. Carburetor for explosion engines.
*774,079. Nov. 1, 1904. Jager. Vaporizing carburetor for internal-combustion engines.
*783,902. Feb. 28, 1905. Shipman. Carburetor for explosive engines.
*785,558. Mar. 21, 1905. Krebs. Oil engine.
*785,622. Mar. 21, 1905. Longuemare. Carburetor for hydrocarbon engines.
*790,173. May 16, 1905. Biehn. Carburetor for explosive engines.
*791,447. June 6, 1905. Breath. Atomizer for internal-combustion engines.
*792,628. June 20, 1905. Sturtevant. Carburetor for gas engines.
*796,723. Aug. 8, 1905. Hewitt. Carburetor.
*799,791. Sept. 19, 1905. Hitchcock. Vaporizer for hydrocarbon engines.
*800,647. Oct. 3, 1905. Hatcher. Carburetor.
*802,216. Oct. 17, 1905. Johnston. Carburetor for hydrocarbon engines.
*806,830. Dec. 12, 1905. Packard. Mixer and vaporizer for hydrocarbon engines.
*810,792. Jan. 23, 1906. McIntosh. Carburetor.
*813,653. Feb. 27, 1906. Law. Carburetor.
*820,583. May 15, 1906. Longuemare. Carburetor for hydrocarbon engines.
*822,681. June 5, 1906. Middleton. Carburetor for gasoline engines.
*831,547. Sept. 25, 1906. Dunlop. Carburetor for explosive engines.
*831,832. Sept. 25, 1906. Coffin. Carburetor for hydrocarbon engines.
*835,564. Nov. 13, 1906. Shain. Vaporizer or carburetor.
*835,880. Nov. 13, 1906. Clément. Carburetor.
*838,085. Dec. 11, 1906. Cook. Carburetor for explosive engines.
*840,204. Jan. 1, 1907. Franquist. Carburetor.
*844,894. Feb. 19, 1907. Renault. Carburetor.
*848,170. Mar. 26, 1907. Hedstrom. Carburetor.
*850.339. Apr. 16, 1907. Bowers. Carburetor for gasoline engines.
*855,170. May 28, 1907. Gray. Carburetor.
*855,574. June 4, 1907. Henabray. Carburetor.
*856,958. June 11, 1907. Huber. Carburetor for hydrocarbon engines.
*857,275. June 18, 1907. Gaither. Carburetor.
860,522. July 16, 19$7. Brown. Carburetor.
*860,848. July 23, 1907. Bowers. Carburetor.
*860,908. July 23, 1907. Enrico. Carburetor for oil engines.
*861,438. July 30, 1907. Cushman. Carburetor.
*864,687. Aug. 27, 1907. Radcliffe. Vaporizer.

*865,539. Sept. 10, 1907. Stewart. Carburetor.
*868,251. Oct. 15, 1907. Bollée. Carburetor.
*868,265. Oct. 15, 1907. Hartford. Carburetor for internal-combustion engines.
*869,675. Oct. 29, 1907. Winton. Gasoline carburetor.
*870,052. Nov. 5, 1907. Schebler. Carburetor.
*875,716. Jan. 7, 1908. Longuemare. Carburetor for explosive engines.
*876,287. Jan. 7, 1908. Williams. Carburetor.
877,136. Jan. 21, 1908. Stewart. Carburetor.
*878,411. Feb. 4, 1908. Winton. Carburetor for internal-combustion engines.
*882,023. Mar. 17, 1908. Shain. Vaporizer or carburetor for gas engines.
*886,265. Apr. 28, 1908. Speed. Rapid-fire carburetor.
*886,760. May 5, 1908. Brush. Carbureting mechanism for internal-combustion engines.
*888,487. May 26, 1908. Greuter. Carburetor.
*888,965. May 26, 1908. Delaunay-Belleville. Automatic carburetor for explosive motors.
*890,494. June 9, 1908. Byron. Carburetor.
*896,559. Aug. 18, 1908. Longuemare. Air inlet for carburetor.
*899,109. Sept. 22, 1908. Heitger. Carburetor.
*900,731. Oct. 13, 1908. Heitger. Carburetor.
*910,379. Jan. 19, 1909. Hedstrom. Carburetor.
*911,105. Feb. 3, 1909. Abel. Carburetor.
*911,692. Feb. 9, 1909. Andrew. Carburetor.
*912,083. Feb. 9, 1909. Daley. Carburetor for internal-combustion engines.
*916,103. Mar. 23, 1909. Cartwright. Carburetor for explosive engines.
916,214. Mar. 23, 1909. Stewart. Controller for carburetors.
*920,642. May 4, 1909. Pfänder. Automatically governed carburetor.
*921,410. May 11, 1909. Kaley. Carburetor.
*924,200. June 8, 1909. Stewart. Carburetor.
*925,978. June 22, 1909. Winton & Anderson. Carburetor.
*926,533. June 29, 1909. Winton & Anderson. Carburetor.
*926,598. June 29, 1909. Perry. Carburetor.
*927,529. July 14, 1909. Harrington. Carburetor.
*928,042. July 13, 1909. Goldberg. Carburetor.
*929,260. July 27, 1909. Stevens. Carburetor.
*929,327. July 27, 1909. Rinke. Carburetor.
*932,860. Aug. 31, 1909. Grouvelle & Arquembourg. Carburetor for internal-combustion engines.
*938,894. Nov. 2, 1909. Rapp. Carburetor.
*942,977. Dec. 14, 1909. Simonson. Carburetor.
*943,197. Dec. 14. 1909. Miller. Carburetor.
*943,242. Dec. 14, 1909. Fergusson & Sheppy. Carburetor.
*944,048. Dec. 21, 1909. Price. Carburetor.
*956,882. May 3, 1910. Bright. Carburetor.
*960,080. May 31, 1910. Fay & Ellsworth. Carburetor.
960,084. May 31, 1910. Friedenwald & ———. Auxiliary air valve for charge-forming devices.
*961,590. June 14, 1910. England. Valve for carburetors and other apparatus.
*968,597. Aug. 30, 1910. Parkin. Carburetor.
*970,916. Sept. 20, 1910. Gerken. Carburetor for gas engines.
*971,689. Oct. 4, 1910. Schebler. Carburetor.
*973,056. Oct. 18, 1910. Mader. Carburetor valve.
*973,755. Oct. 25, 1910. Carter. Carburetor.
*973,877. Oct. 25, 1910. Pierce. Carburetor.
*976,558. Nov. 22, 1910. Dayton. Air-controlling mechanism for carburetors.
*977,377. Nov. 29, 1910. Donnelly et al. Triple auxiliary air valve for carburetors.
*981,156. Jan. 10, 1911. Barker. Carburetor.
*984,276. Feb. 14, 1911. Kelly. Carburetor.
*985,670. Feb. 28, 1911. Grouvelle et al. Carburetor.
*989,697. Apr. 18, 1911. Cutler. Carburetor.
*992,260. May 16, 1911. Rush. Vaporizer and separator.
*995,919. June 20, 1911. Smith. Carburetor.
*995,976. June 20, 1911. Maud. Carburetor.
*996,897. July 4, 1911. Swarts. Carburetor.
*996,981. July 4, 1911. Folberth. Carburetor.
*997,169. July 4, 1911. Winton & Anderson. Carburetor.

*997,233. July 4, 1911. Bowers. Carburetor.
*1,000,054. Aug. 8, 1911. Ulrich. Carburetor.
*1,001,969. Aug. 29, 1911. Maynard. Carburetor.
*1,003,994. Sept. 29, 1911. Dennis. Carburetor.
1,004,031. Sept. 29, 1911. Iver. Force-feed carburetor.
*1,055,300. Oct. 10, 1911. Pierce. Carburetor.
*1,006,033. Oct. 17, 1911. Ter Weer. Carburetor.
*1,006,663. Oct. 24, 1911. Kugler. Carburetor.
*1,010,714. Dec. 5, 1911. Zisch. Carburetor.
*1,013,082. Dec. 26, 1911. Symmonds. Carburetor.
*1,018,126. Feb. 20, 1912. Nageborn. Carburetor.
*1,018,164. Feb. 20, 1912. Chapin. Carburetor.
*1,018,766. Feb. 27, 1912. Kerr. Carburetor.
*1,018,776. Feb. 27, 1913. Plein. Carburetor.
*1,019,128. Mar. 5, 1912. Bulock. Carburetor.
*1,019,160. Mar. 5, 1912. Ivor. Carburetor.
*1,020,059. Mar. 12, 1912. Schulz. Carburetor.
*1,022,326. Apr. 2, 1912. Namur. Carburetor.
*1,035,937. Aug. 20, 1912. Anderson. Carburetor.
*1,038,050. Sept. 10, 1912. Wills. Carburetor.
*1,038,262. Sept. 10, 1912. Anstice. Carburetor.
*1,038,699. Sept. 17, 1912. Wilkinson. Carburetor.
*1,041,099. Oct. 15, 1912. Kerns. Carburetor.
*1,041,480. Oct. 15, 1912. Kaley. Carburetor.
*1,042,004. Oct. 22, 1912. Ivor. Carburetor.
*1,042,982. Oct. 29, 1912. Sliger. Carburetor.
*1,043,692. Nov. 5, 1912. Grath. Carburetor.
*1,044,245. Nov. 12, 1912. Reedy. Carburetor.
*1,044,569. Nov. 18, 1912. Perrin. Carburetor.
*1,044,576. Nov. 19, 1912. Russell. Carburetor.
*1,044,594. Nov. 19, 1912. Stroud. Carburetor.
*1,046,344. Dec. 3, 1912. Stewart. Carburetor.
*1,052,897. Feb. 11, 1913. Dayton. Carburetor.
*1,052,917. Feb. 11, 1913. Heitger. Carburetor.
*1,053,145. Feb. 18, 1913. Ball. Carburetor.
*1,055,352. Mar. 11, 1913. Pembroke. Carburetor.
*1,059,368. Apr. 22, 1913. Johnson. Carburetor.
*1,062,273. May 20, 1913. Conklin. Carburetors.
*1,062,688. May 27, 1913. Bastian. Carburetors.
*1,064,446. June 10, 1913. Comstock. Carburetor.
*1,067,502. July 15, 1913. Browne. Carburetor.
*1,069,671. Aug. 12, 1913. Brush. Carburetor.
*1,071,858. Sept. 2, 1913. Ball. Carburetor.
*1,073,473. Sept. 16, 1913. Claudel. Carburetor.
*1,073,695. Sept. 23, 1913. Marr. Carburetor.
*1,076,827. Oct. 28, 1913. Haynes. Carburetor.
*1,078,169. Nov. 11, 1913. Schreiber. Carburetor.
*1,080,166. Dec. 2, 1913. Pribil. Carburetor.
*1,080,645. Dec. 9, 1913. Mayer. Carburetor.
*1,086,287. Feb. 3, 1914. Gehrmann. Carburetor.
*1,089,423. Mar. 10, 1914. Mayer. Carburetor.
*1,090,556. Mar. 17, 1914. Mégevit & Picker. Carburetor for internal-combustion engines.
*1,092,282. Apr. 7, 1914. Mixsell. Carburetor.
*1,093,627. Apr. 21, 1914. Johnson. Carburetor.
*1,093,901. Apr. 21, 1914. Wyman. Carburetor.
*1,095,212. May 5, 1914. Johnson. Carburetor.
*1,095,326. May 5, 1914. Huff. Carburetor.
*1,096,569. May 12, 1914. Sharpneck. Carburetor.
*1,099,714. June 9, 1914. Munden. Carburetor.
*1,104,975. July 28, 1914. Felske. Carburetor.
*1,105,134. July 28, 1914. Hanemann. Carburetor.
*1,106,145. Aug. 4, 1914. Hazelton. Carburetor.
*1,106,226. Aug. 4, 1914. Lamb. Carburetor.
*1,106,802. Aug. 11, 1914. Goldberg. Carburetor.
*1,107,693. Aug. 18, 1914. Molina. Carburetor.
*1,107,849. Aug. 18, 1914. Schoen. Carburetor.

109,356. Sept. 1, 1914. Mycue. Carburetor.
110,041. Sept. 8, 1914. Christian. Carburetor.
10,482. Sept. 15, 1914. Collier. Carburetor.
13,533. Oct. 13,1914. Barrett. Carburetor.
15,543. Nov. 3, 1914. Huguelet. Carburetor.
16,673. Nov. 10, 1914. De Clairmont. Air-valve control for carburetors.
19,078. Dec. 1, 1914. Goldberg. Carburetor.
19,757. Dec. 1, 1914. Kings. Carburetor.
20,303. Dec. 8, 1914. Georgenson. Carburetor.
22,572. Dec. 29, 1914. Blackert. Carburetor.
24,918. Jan. 12, 1915. Krause. Carburetor.
26,218. Jan. 26, 1915. Howe. Carburetor.
27,992. Feb. 9, 1915. Hartshorn. Carbureto..
29,864. Mar. 2, 1915. Haas. Carburetor.
31,584. Mar. 9, 1915. Wildy. Spray carburetor.
34,531. Apr. 6, 1915. Heitger. Carburetor.
34,532. Apr. 6, 1915. Heitger. Carburetor.
41,086. May 25, 1915. Kent. Carburetor.
45,138. July 6, 1915. Goldberg. Carburetor.
48,461. July 27, 1915. Russell. Carburetor.
56,149. Oct. 12, 1915. Kingston. Carburetor.
59,423. Nov. 9, 1915. Schulte. Carburetor.
66,595. Jan. 4, 1916. Johnson. Carburetor.
67,320. Jan. 4, 1916. Thomas. Carburetor.
71,401. Feb. 8, 1916. Purcell. Carburetor.
72,388. Feb. 22, 1916. Prescott. Carburetor.
72,432. Feb. 22, 1916. Clark. Carburetor.
76,729. Mar. 21, 1916. Flechter. Carburetor.
77,318. Mar. 28, 1916. Goldberg. Carburetor.
79,386. Apr. 18, 1916. Anderson. Carburetor.
80,379. Apr. 25, 1916. Dayton. Carburetor.
80,389. Apr. 25, 1916. Friend. Carburetor.
83,137. May 16, 1916. Swarts. Carburetor.
6,166. June 6, 1916. Bennett. Carburetor.
6,584. June 13, 1916. Kingston. Carburetor. (Withdrawn.)
85,273. May 30, 1916. Atherton. Carburetor.
. 13,784 (orig. 1,067,502). Aug. 4, 1914. Browne. Carburetor.
. 13,837 (orig. 1,042,982). Dec. 1, 1914. Sliger. Carburetor.

Cross-reference patents, class 48, subclass 155.2.

951,002	981,853	1,006,130	1,017,750	1,030,343	1,042,017	1,059,501
955,956	982,297	1,009,121	1,020,270	1,033,443	1,044,314	1,061,995
973,855	983,836	1,010,185	1,022,702	1,036,301	1,046,111	1,064,867
976,344	985,122	1,010,003	1,022,703	1,036,536	1,046,141	1,065,331
976,881	993,065	1,011,641	1,023,470	1,037,834	1,049,887	
979,555	1,001,847	1,011,960	1,027,768	1,040,528	1,051,440	
,066,508	1,078,591	1,085,194	1,112,641	1,130,502	1,138,204	1,149,323
,067,623	1,078,592	1,085,239	1,114,222	1,132,934	1,139,914	1,152,134
,069,389	1,079,338	1,086,226	1,122,703	1,134,942	1,140,525	1,155,829
,073,727	1,080,696	1,087,187	1,120,573	1,135,270	1,141,796	1,156,823
,076,309	1,081,258	1,087,218	1,120,763	1,135,689	1,143,092	1,157,541
,077,256	1,084,028	1,095,402	1,125,525	1,136,368	1,145,172	1,158,435
,078,413	1,084,693	1,097,787	1,126,249	1,137,135	1,147,672	
,078,590	1,084,954	1,103,864	1,128,773	1,137,727	1,149,291	

SUBCLASS 156, CARBURETORS, CAPILLARY.

74. Nov. 6, 1866. Stevens. Improved apparatus for carbureting air.
70. Jan. 1, 1867. Bassett. Improved capillary material for filling gas and air carburetors.
31. Apr. 30, 1867. Porter. Improved apparatus for carbureting gas and air.
36. June 25, 1867. Bassett. Improvement in gas carburetors.
74. Sept. 8, 1868. Bassett. Apparatus for the manufacturing of heating and illuminating gas.

83,748. Nov. 3, 1868. Williams. Improvement in charging gases with vapors of hydrocarbon liquids.
94,898. Sept. 14, 1869. La Fronge. Improved apparatus for carbureting air.
96,842. Nov. 16, 1869. Shaler. Improved apparatus for carbureting air.
108,432. Oct. 18, 1870. Bartholf. Improvement in apparatus for carbureting air and gases.
109,148. Nov. 8, 1870. Spang. Improvement in apparatus for carbureting air.
113,968. Apr. 25, 1871. Beers. Improvement in apparatus for carbureting air.
116,563. July 4, 1871. Coons. Improvement in carburetors for gas and air.
142,545. Sept. 2, 1871. Lockwood. Improvement in charburetors.
148,579. Mar. 17, 1874. Sloper. Improvement in apparatus for carbureting air and gas.
156,513. Nov. 3, 1874. Venner & Judy. Improvement in gas carburetors.
158,802. Jan. 19, 1875. Martin. Improvement in gas carbureting machines.
166,602. Aug. 10, 1875. Gearing. Improvement in carbureting apparatus.
168,797. Oct. 11, 1875. Snow. Improvement in carburetors.
169,034. Oct. 19, 1875. Pollard. Improvement in carburetors.
169,872. Nov. 9, 1875. Werni. Improvement in carbureting apparatus.
180,061. July 18, 1876. Pollard. Improvement in carburetors.
181,727. Aug. 29, 1876. Schmidt. Improvement in carburetors.
185,957. Jan. 2, 1877. Peacock & Bradley. Improvement in carburetors.
198,731. Dec. 25, 1877. Merritt. Improvement in carburetors.
203,505. May 7, 1878. Sloper. Improvement in carburetors.
203,702. May 14, 1878. Buell. Improvement in apparatus for carbureting air and gas.
207,983. Sept. 10, 1878. Reid. Improvement in carbureting apparatus.
209,076. Oct. 15, 1878. Reznor. Improvement in air carburetors.
209,351. Oct. 29, 1878. Merritt. Improvement in purifier and regulator for carburetors.
210,019. Nov. 19, 1878. Dougherty. Improvement in carburetors.
211,744. Jan. 28, 1879. Keller. Improvement in carburetors.
213,931. Apr. 1, 1879. Pew. Improvement in carbureting apparatus for air and gas.
219,705. Sept. 16, 1879. Fleming. Improvement in carburetors.
220,001. Sept. 23, 1879. Train. Improvement in gas carburetors.
221,948. Nov. 25, 1879. Wayland. Carburetor.
234,955. Nov. 30, 1880. Burrows. Carbureting apparatus.
236,159. Jan. 4, 1881. Howe & Miner. Apparatus for carbureting air.
241,419. May 10, 1881. Reynolds. Apparatus for obtaining an illuminating and heating gas.
246,601. Sept. 6, 1881. Copeland. Carbureting apparatus.
247,390. Sept. 30, 1881. Morey. Carburetor.
251,416. Dec. 27, 1881. Crowell. Carbureting apparatus.
253,202. Feb. 7, 1882. Haberstick. Carburetor.
256,741. Apr. 18, 1882. Reynolds. Gas-generating apparatus.
261,852. Aug. 1, 1882. Ives. Means for producing the oxyhydrogen blowpipe flame.
292,622. Jan. 29, 1884. Billings. Apparatus for producing gas.
304,507. Sept. 2, 1884. Dillenbeck. Gas machine.
397,631. Feb. 12, 1889. Carsley. Vaporizer.
398,225. Feb. 19, 1889. Bury & Bidelman. Carburetor.
420,591. Feb. 4, 1890. Dawson. Carburetor.
450,091. Apr. 7, 1891. Woolley. Vaporizer for gas engines.
476,709. June 7, 1892. Weaver. Carburetor and purifier.
486,442. Nov. 22, 1892. Enos. Carburetor.
493,992. Mar. 21, 1893. Fontaine. Apparatus for carbureting air.
566,415. Aug. 25, 1896. Schroeder. Carburetor.
590,640. Sept. 28, 1897. Byrne. Carburetor.
620,586. Mar. 7, 1899. Henderson. Carburetor.
650,276. May 22, 1900. Robinson. Carburetor.
660,125. Oct. 23, 1900. Schimdt. Carburetor.
663,699. Dec. 11, 1900. Latham. Carburetor.
669,317. Mar. 5, 1901. Brown. Carburetor.
709,866. Sept. 30, 1902. Bouchaud-Praceiq. Carburetor.
716,716. Dec. 23, 1902. Jenney. Gas generator.
720,485. Feb. 10, 1903. Robinson. Carburetor.
721,268. Feb. 24, 1903. Wolff. Carburetor.

3,074. June 21, 1904. Ruthven. Carburetor.
5,108. July 12, 1904. Soeder. Carburetor.
2,551. Oct. 18, 1904. Akeson. Carburetor.
1,486. Nov. 8, 1904. Marshall. Carburetor.
5,859. Nov. 22, 1904. Russell. Means for carbureting air.
2,619. Feb. 14, 1905. Mossig. Portable carburetor.
1,938. July 18, 1905. Houlon. Carburetor.
3,397. Apr. 17, 1906. Tresenreuter. Carburetor.
5,336. July 10, 1906. McCormick. Carburetor.
9,540. Dec. 25, 1906. Berg. Blowpipe apparatus.
3,028. Feb. 5, 1907. Mueller. Carburetor.
7,362. Mar. 19, 1907. Paris. Apparatus for manufacture of gas.
3,196. May 7, 1907. Akeson & Anderson. Carburetor.
3,654. June 11, 1907. McCormick & Miller. Carburetor.
9,334. July 16, 1907. Schell. Carburetor.
5,265. Apr. 21, 1908. Loewenstein. Carburetor.
3,190. May 19, 1908. Odell. Carburetor for hydrocarbon engines.
9,207. Jan. 19, 1909. Keep. Carburetor.
3,456. Feb. 23, 1909. Bertrand & Goubillon. Carburetor.
1,367. Sept. 14, 1909. Steel. Carburetor.
2,503. Dec. 7, 1909. Jacobs. Carburetor for hydrocarbon engines.
9,761. Dec. 27, 1910. Haywood. Carburetor.
5,122. Feb. 28, 1911. Ashmusen. Carburetor.
5,515. Feb. 28, 1911. Dorman. Carburetor.
25,558. May 7, 1912. Williams. Carburetor.
33,443. July 23, 1912. Morris & Merritt. Carburetor.
62,180. May 20, 1913. Meyers. Carburetor.
73,727. Sept. 23, 1913. Atwood. Carburetor.
76,309. Oct. 21, 1913. Patterson & Percival. Carburetor.
82,865. Dec. 30, 1913. Goodyear. Carburetor.
89,501. Mar. 10, 1914. Ruthven. Carburetor.
96,750. May 12, 1914. Pond. Carburetor.
97,039. May 19, 1914. Miller. Carburetor.
05,871. July 28, 1914. Omer. Carburetor.
46,625. July 13, 1915. Sanders. Carburetor.
52,915. Sept. 7, 1915. Huszär. Carburetor.
67,290. Jan. 4, 1915. Glover. Carburetor.
190,124. July 4, 1916. Lukacsevics & Terrill. Carburetor.
190,125. July 4, 1916. Lukacsevics. Carburetor.
191,156. July 18, 1916. Ciglia & Pelletier. Suction intensifying carburetor.
191,522. July 18, 1916. Lamb. Carburetor.
91,097. July 11, 1916. Spiers. Carburetor.
. 6,004 (orig. 142,545). Aug. 11, 1874. Lockwood. Carburetor.

Cross-reference patents, class 48, subclass 156.

57,639	138,715	210,717	427,197	688,931	846,679	1,004,661
65,296	143,534	222,822	429,426	697,807	852,780	1,009,121
66,068	150,827	242,379	488,454	706,482	854,604	1,024,501
67,216	167,150	249,160	522,418	712,803	860,334	1,060,545
73,900	169,423	288,868	538,791	768,063	886,403	1,069,068
81,590	Re. 6,878	308,693	541,441	772,673	913,857	1,075,598
87,556	176,156	312,512	548,689	788,427	933,064	1,076,401
89,536	176,395	336,574	596,658	793,776	951,779	1,104,560
Re. 3,779	191,789	340,221	598,393	810,087	964,165	1,105,160
110,005	192,399	378,647	628,222	813,796	973,240	1,173,469
115,182	193,911	403,377	635,456	817,592	982,490	
133,957	204,413	423,393	662,922	844,996	989,980	

SUBCLASS 157, CARBURETORS, CAPILLARY, SPIRAL PASSAGE.

829. Sept. 30, 1856. Varney. Hydrocarbon-vapor lamp.
534. June 15, 1858. Absterdam. Apparatus for manufacturing gas.
771. Mar. 14, 1865 Bassett. Improved apparatus for carbureting air.
021. Nov. 10, 1868. Thompson. Improved gas machine.
588. June 22, 1869. Alsop. Improved apparatus for manufacturing illuminating gas.

123,539. Feb. 6, 1872. Wilkinson. Improvement in carburetors.
126,189. Apr. 30, 1872. Cross. Improvement in carburetors.
149,766. Apr. 14, 1874. Palmer. Improvement in carburetors.
160,410. Mar. 2, 1875. Ferguson. Improvement in carburetors or hydrocarbon diffusers.
163,528. May 18, 1875. Reed. Improvement in gas carburetors.
172,074. Jan. 11, 1876. Barbarin & Roberts. Improvement in carburetors.
184,220. Nov. 7, 1876. De St. Aubin. Improvement in carburetors.
224,592. Feb. 17, 1880. Heywood & Boeklen. Carbureting apparatus.
238,020. Feb. 22, 1881. Anthony & Frost. Apparatus for producing illuminating gas or vapor.
238,386. Mar. 1, 1881. Guthrie. Carburetor.
261,011. July 11, 1882. Matthews & Holt. Gas machine.
286,865. Oct. 16, 1883. Taylor. Gas machine.
341,739. May 11, 1886. Fagan. Hydrocarbon-vapor stove.
375,055. Dec. 20, 1887. Dudley. Carburetor.
385,934. July 10, 1888. Ives. Caturator for the production of vapor blowpipe flames.
675,566. June 4, 1901. Lawrence. Carburetor.
699,965. May 13, 1902. Mangin. Carburetor.
780,673. Jan. 24, 1905. Lawrence. Carburetor.
798,418. Aug. 29, 1905. Johnson. Carburetor.
839,116. Dec. 25, 1906. Compton. Carburetor.
990,159. Apr. 18, 1911. Olsen. Carburetor.
Re. 3,124 (orig. 46,771). Sept. 15, 1868. Bassett. Improvement in apparatus for carbureting air or gases.

Cross-reference patents, class 48, subclass 157.

55,324	170,097	385,934	746,173	767,485	883,171	1,025,553
115,988	193,232	501,778	759,539	798,150	969,941	Re. 4,476
156,142	224,576					

SUBCLASS 158, CARBURETORS, CAPILLARY, VERTICAL SCREEN.

46,432. Feb. 14, 1865. Buckland. Improved apparatus for carbureting air.
48,706. July 11, 1865. Birchard. Improved apparatus for carbureting air.
49,705. Sept. 5, 1865. Boynton. Improved gaslight multiplier.
53,798. Apr. 10, 1866. Fairbanks. Improved apparatus for carbureting air.
55,778. June 19, 1866. Messenger. Improved apparatus for carbureting air, gas, etc.
57,686. Sept. 4, 1866. Divine. Improved apparatus for carbureting air.
57,729. Sept. 4, 1866. Johnston. Improved apparatus for carbureting gas.
57,812. Sept. 4, 1866. Worrall. Improved apparatus for carbureting gas.
58,209. Sept. 23, 1866. Boynton. Improved apparatus for carbureting gas.
58,861. Oct. 16, 1866. McGreary. Improved apparatus for carbureting air.
60,857. Jan. 1, 1867. Burridge. Improved apparatus for charging gas or air with hydrocarbon vapor.
61,309. Jan. 22, 1867. Boynton. Improved apparatus for carbureting gas and air.
69,621. Oct. 8, 1867. Boynton. Improved gaslight multiplier.
70,512. Nov. 5, 1867. Boynton. Improvement in carbureting gases and air.
78,185. May 26, 1868. Childs. Improved gas apparatus.
81,238. Aug. 18, 1868. Woodward. Improvement in apparatus for carbureting.
90,445. May 25, 1869. Groat. Improved gas machine.
100,274. Mar. 1, 1870. Dunderdale. Improved carburetor.
107,262. Sept. 13, 1870. Hyde. Improvement in apparatus for carbureting air and gas.
112,026. Feb. 21, 1871. Fisher. Improvement in apparatus for carbureting and generating gas.
127,409. June 4, 1872. Fisher. Improvement in carburetors.
128,356. June 25, 1872. Braun. Improvement in carburetors.
129,566. July 16, 1872. Hyde. Improvement in carburetors.
135,806. Feb. 11, 1873. Holmes. Improvement in carbureting apparatus.
147,244. Feb. 10, 1874. Davey & Griswold. Improvement in carburetors.

148,602. Mar. 17, 1874. Fisher & Darby. Improvement in carbureting apparatus.
156,820. Nov. 10, 1874. Reed. Improvement in gas carburetors.
164,423. June 15, 1875. Caldwell. Improvement in machines for manufacturing vapor gas.
172,144. Jan. 11, 1876. Meredith. Improvement in carburetors.
176,425. Apr. 25, 1876. Caldwell. Improvement in gas carburetors.
193,561. July 24, 1877. Siré. Improvement in apparatus for carbureting gas.
205,201. June 25, 1878. Morehouse. Improvement in carburetors.
209,505. Oct. 29, 1878. Otten & Kluber. Improvement in apparatus for carbureting illuminating gas.
216,191. June 3, 1879. Keller. Improvement in gas carburetors.
219,590. Sept. 16, 1879. Morehouse. Improvement in carburetors.
220,695. Oct. 21, 1879. Bean. Improvement in carburetors.
223,490. Jan. 13, 1880. De Witt. Carburetors.
226,820. Apr. 20, 1880. Ferguson. Gas carburetor.
237,752. Feb. 15, 1881. Keller. Gas carburetor.
259,921. June 20, 1882. Reznor. Air carburetor.
268,910. Dec. 12, 1882. Lacy. Carburetor.
278,529. May 29, 1883. Frost. Apparatus for producing illuminating gas or vapor.
286,515. Oct. 9, 1883. Weston. Apparatus for increasing the illuminating power of gas.
300,757. June 24, 1884. Bois. Gas apparatus.
312,186. Feb. 10, 1885. Butler. Apparatus for carbureting air and gas.
354,574. Dec. 21, 1886. O'Connor. Carburetor.
359,585. Mar. 15, 1887. Weil. Carburetor.
366,664. July 19, 1887. Hickel. Gas carburetor.
382,819. May 15, 1888. Marks. Carburetor.
431,059. July 1, 1890. Keller. Carburetor.
440,486. Nov. 11, 1890. Love. Carburetor.
457,484. Aug. 11, 1891. Stringfellow. Apparatus for the manufacture of gas.
473,498. Apr. 26, 1892. Cruttenden. Carburetor.
499,635. June 13, 1893. Keller. Carburetor.
501,154. July 11, 1893. McCrory & Houze. Carburetor.
515,287. Feb. 20, 1894. Cabrié-Gardien. Carburetor.
522,574. July 3, 1894. Burrows. Carburetor.
522,968. July 17, 1894. Clarke & Griffen. Apparatus for carbureting air.
550,317. Nov. 26, 1895. Callahan. Carburetor.
589,094. Aug. 31, 1897. Ormerod. Carburetor.
590,893. Sept. 28, 1897. Ladd. Method of and apparatus for manufacturing gas.
620,496. Feb. 28, 1899. Ravenèz. Carburetor.
626,176. May 30, 1899. Logan. Carburetor.
633,287. Sept. 19, 1899. Lewis & Bailey. Carburetor.
661,697. Nov. 13, 1900. Jeffery. Carburetor.
666,483. Jan. 22, 1901. Wilkinson. Carburetor.
678,493. July 16, 1901. Jackson. Carburetor.
680,941. Aug. 20, 1901. Sargent. Carburetor.
699,357. May 6, 1902. Wilkinson et al. Carburetor.
717,444. Dec. 30, 1902. Nagel. Carburetor.
725,148. Apr. 14, 1903. Ruthven. Carburetor.
726,671. Apr. 28, 1903. Gemmer. Vaporizer for explosive engines.
750,311. Jan. 26, 1904. Severance. Carburetor.
765,351. July 19, 1904. Avery & Smith. Carburetor.
773,682. Nov. 1, 1904. Severance. Carburetor.
777,220. Dec. 13, 1904. Patee. Carburetor for explosive engines.
778,686. Dec. 27, 1904. Loewenstein. Carburetor.
783,648. Feb. 28, 1905. Severance et al. Carburetor.
796,557. Aug. 8, 1905. Bockoven. Carburetor.
801,044. Oct. 3, 1905. Parsons. Carburetor for hydrocarbon engines.
820,036. May 8, 1906. Burch. Carburetor.
827,643. July 31, 1906. Lawrence. Carburetor.
832,547. Oct. 2, 1906. Hooper. Carburetor.
843,112. Feb. 5, 1907. Severance. Carburetor.
863,154. Aug. 13, 1907. Cox. Carburetor.

887,017. May 5, 1908. Puddington. Carburetor.
982,490. Jan. 24, 1911. Haywood. Carburetor.
1,011,244. Dec. 12, 1911. Puddington. Carburetor.
1,046,653. Dec. 10, 1912. Ruthven. Carburetor.
1,063,900. June 3, 1913. Whitacre. Carburetor.
1,065,331. June 17, 1913. Rubesky. Carburetor.
1,070,514. Aug. 19, 1913. Myers. Carburetor.
1,093,718. Apr. 21, 1914. Myers. Carburetor.
1,104,427. July 21, 1914. Kendall. Apparatus for carbureting air.
1,116,861. Nov. 10, 1914. Wilson. Carburetor.
1,157,588. Oct. 19, 1915. Rubesky. Carburetor.
Re. 2,375 (48,705). Oct. 16, 1866. Boynton. Improvement in apparatus for carbureting gas.
Re. 2,376 (58,209). Oct. 16, 1866. Boynton. Improved apparatus for carbureting gas.

Cross-reference patents, class 48, subclass 158.

31,720	115,798	177,909	207,886	451,036	692,518	951,779
35,984	128,321	190,673	226,875	509,174	734,772	979,761
45,729	132,132	191,381	252,307	528,882	779,906	994,985
46,770	133,118	192,825	278,281	563,799	832,330	1,089,471
48,391	140,998	193,934	303,927	595,658	843,554	
54,132	163,535	197,944	336,572	623,725	857,130	
107,743	177,191	206,999	424,654	626,193	855,407	

SUBCLASS 159, CARBURETORS, CAPILLARY, ZIGZAG PASSAGE.

26,458. Dec. 13, 1859. Bronson. Hydrocarbon-vapor apparatus.
49,596. Aug. 22, 1865. Mille. Improved apparatus for carbureting air.
56,503. July 17, 1866. Wright. Improved apparatus for carbureting gas.
60,417. Dec. 11, 1866. Pickering. Improved apparatus for charging air with gasoline.
83,730. Nov. 3, 1868. Richard. Improved apparatus for carbureting air.
84,814. Dec. 8, 1868. Foster & Ganster. Improved apparatus for illuminating railroad cars, steamers, etc.
92,635. July 13, 1869. Nichols. Improved carburetor for air and gas.
106,389. Aug. 16, 1870. Millward. Improvement in carbureting apparatus.
114,538. May 2, 1871. Simonds. Gas machine.
126,024. Apr. 23, 1872. Coleman. Improvement in gas carburetors.
131,157. Sept. 10, 1872. Fell. Improvement in carbureting illuminating gas.
143,426. Oct. 7, 1873. Sloper. Improvement in portable gas machines.
145,248. Dec. 2, 1873. Simmons. Improvement in carburetors.
151,625. June 2, 1874. Ruthven. Improvement in carburetors.
167,592. Sept. 7, 1875. Westcott. Improvement in carburetors.
181,666. Aug. 29, 1876. Geisenberger. Improvement in carburetors.
203,371. May 7, 1878. Reed. Improvement in carburetors.
203,458. May 7, 1878. Hughes. Improvement in carburetors.
214,711. Apr. 22, 1879. Ruthven. Improvement in carburetors and regulators.
229,346. June 29, 1880. Westinghouse. Carburetor.
231,635. Aug. 24, 1880. West. Apparatus for carbureting air or gases for illuminating purposes.
281,108. July 10, 1883. Mills. Carburetor.
312,836. Feb. 24, 1885. Frost. Carburetor.
315,747. Apr. 14, 1885. Detwiler. Gas generator.
328,359. Oct. 13, 1885. Stubbers. Automatic gas machine.
341,299. May 4, 1886. Wolford. Carburetor.
356,337. Jan. 18, 1887. Stanour. Carburetor.
359,646. Mar. 22, 1887. Sumerwell. Carburetor.
366,168. July 5, 1887. Huber. Gas-generating machine.
427,487. May 6, 1890. Tibbets. Carburetor.
683,401. Sept. 24, 1901. Houze. Carburetor.
710,330. Sept. 30, 1902. Marks. Carburetor for explosive engines.
712,169. Oct. 28, 1902. Wright. Carburetor.
730,627. June 9, 1903. Esser. Carburetor.
756,381. Apr. 5, 1904. Lawrence. Carburetor.
773,679. Nov. 1, 1904. Sale & Hoag. Carburetor.

783,790. Feb. 28, 1905. Kline. Gas-enriching machine.
817,218. Apr. 10, 1906. Brown. Carburetor.
818,207. Apr. 17, 1906. Verret & Palmer. Carburetor.
838,719. Dec. 18, 1906. Kelley. Carburetor.
964,165. July 12, 1910. Kelley. Carburetor.
975,635. Nov. 15, 1910. Potthast. Carburetor.
1,050,322. Jan. 14, 1913. Woodworth. Carburetor.
1,075,396. Oct. 14, 1913. Boatwright. Oil burner.
1,106,070. Aug. 4, 1914. Andres. Carburetor.
1,164,215. Dec. 14, 1915. Rodrigues & Schmitt. Carburetor.

Cross-reference patents, class 48, subclass 159.

131,815	221,680	353,499	725,148	773,682	820,036	959,350
154,475	291,676	395,152	763,965	780,355	820,554	944,482
164,360	327,981	423,367	765,351	783,648	863,154	1,070,514
168,048	336,378	540,536	787,732	807,131	885,332	1,075,598
Re. 6,865						

SUBCLASS 160, CARBURETORS, GRAVITY.

50,250. Oct. 3, 1865. Irwin. Improved apparatus for carbureting air.
51,841. Jan. 2, 1866. Loveless. Improved apparatus for carbureting air.
52,946. Feb. 27, 1866. Chamberlin. Improved apparatus for carbureting gas for illuminating.
55,950. June 26, 1866. Brown. Improved apparatus for carbureting air.
66,071. June 25, 1867. Bassett. Improvement in the manufacture of illuminating gas.
83,026. Oct. 13, 1868. Bassett. Improvement in gas generators.
177,909. May. 26, 1876. Williams. Improvement in gas-making apparatus.
397,255. Feb. 5, 1889. Stubbers. Gasoline apparatus for illuminating and heating purposes.
421,834. Feb. 18, 1890. Hollingsworth. Apparatus for vaporizing liquid hydrocarbon and supplying the vapors to burners.
448,652. Mar. 24, 1891. Hollingsworth. Vapor stove.
451,050. Apr. 28, 1891. Hollingsworth. Starter for vapor stoves.
454,014. June 9, 1891. Marsh. Vapor stove.
456,510. July 21, 1891. Davis. Apparatus for vaporizing and feeding hydrocarbon.
470,756. Mar. 15, 1892. Hollingsworth. Vapor stove.
471,289. Mar. 22, 1892. Hollingsworth. Vapor stove.
479,315. July 19, 1892. Stockstrom. Vapor stove.
480,281. Aug. 9, 1892. Ruppel. Vapor stove.
483,051. Sept. 20, 1892. Flick. Vapor stove.
489,477. Jan. 10, 1893. Hollingsworth. Vapor stove.
490,085. Jan. 17, 1893. Romoser. Vapor stove.
490,655. Jan. 31, 1893. Hollingsworth. Vapor stove.
490,656. Jan. 31, 1893. Hollingsworth. Vapor stove.
493,186. Mar. 7, 1893. Sayers. Gasoline-burner attachment.
525,331. Sept. 4, 1894. Campany. Vapor burner.
525,350. Sept. 4, 1894. Lindemann. Vapor-burning apparatus.
528,795. Nov. 6, 1894. Palmer & Munro. Gasoline stove.
541,530. June 25, 1895. Goergen. New-process vapor burner.
555,436. Feb. 25, 1896. Davis. Evaporator burner or stove.
555,450. Feb. 25, 1896. Johnson. Vapor stove.
570,482. Nov. 3, 1896. Hutchins. Gasoline stove.
608,388. Aug. 2, 1898. Brown. Gasoline stove.
640,832. Jan. 9, 1900. Thayer. Carburetor.
720,968. Feb. 17, 1903. Rife & Carper. Carburetor.
739,144. Sept. 15, 1903. Blackford. Gasoline burner.
834,614. Oct. 30, 1906. Gray. Carburetor.
944,070. Dec. 21, 1909. Best. Hydrocarbon burner.
952,412. Mar. 15, 1910. Blackford. Gasoline burner.

Cross-reference patents, class 48, subclass 160.

47,257	187,415	490,415	807,131

SUBCLASS 163, CARBURETORS, OSMOTIC.

236,433. Jan. 11, 1881. Hoard. Carburetor.
291,128. Jan. 1, 1884. Baker. Carburetor.
533,275. Jan. 29, 1895. Collet & Merichenski. Carburetor.
625,084. May 16, 1899. Brown & Dixon. Carburetor.
671,052. Apr. 2, 1901. Kurz. Carburetor.

SUBCLASS 164, CARBURETORS, PIVOTED.

66,068. June 25, 1867. Bassett. Improvement in carbureting gases.
78,600. June 2, 1868. Malcolm. Improved apparatus for generating gas.
169,423. Nov. 2, 1875. Covel. Process and apparatus for enriching gas or air with a definite and regulated percentage of hydrocarbon vapor.
188,667. Mar. 20, 1877. Pierce & Smiley. Carburetor.
191,789. June 12, 1877. Winn. Improvement in gas and air carburetors.
192,399. June 26, 1877. Winn. Improvement in gas and air carburetors.
204,413. May 28, 1878. Dusenberry & Winn. Improvement in gas and air carburetors.
294,863. Mar. 11, 1884. Gairing & Lehmann. Carburetor.
Re. 6,878. Jan. 25, 1876. Covel. Improvement in processes and apparatus for manufacturing illuminating gas.

SUBCLASS 165, CARBURETORS, PIVOTED, REVOLVING.

12,535. Mar. 13, 1855. Cuningham. Benzole vapor apparatus.
13,010. June 5, 1855. McDougall. Hydrocarbon-vapor apparatus.
35,144. May 6, 1862. Drake. Improved apparatus for carbureting air.
43,264. June 21, 1864. Simonds. Improved apparatus for carbonizing air for illuminating purposes.
44,060. Sept. 6, 1864. Archer. Improvement in apparatus for carbureting air.
44,560. Oct. 4, 1864. Simonds. Improved apparatus for carbonizing air for illuminating purposes.
50,076. Sept. 19, 1865. McAvoy. Improved apparatus for carbureting air.
50,103. Sept. 26, 1865. Drennan. Improved apparatus for carbureting air.
50,675. Oct. 31, 1865. Bassett. Improved apparatus for carbureting air.
50,905. Nov. 14, 1865. Chase. Improved apparatus for carbureting air.
50,987. Nov. 14, 1865. Chase. Improved apparatus for carbureting air.
51,946. Jan. 9, 1866. Hutchinson & McAvoy. Improved apparatus for carbureting air.
52,087. Jan. 9, 1866. Spence. Improved apparatus for carbureting air.
53,504. Mar. 27, 1866. Thompson. Improved apparatus for carbureting air.
57,164. Aug. 14, 1866. McAvoy. Improved apparatus for carbureting air.
57,442. Aug. 21, 1866. McDonald. Improved apparatus for carbureting air.
57,543. Aug. 28, 1866. Mihan. Improved apparatus for carbureting air.
57,788. Sept. 4, 1866. Spence. Improved apparatus for carbureting air.
61,739. Feb. 5, 1867. Hutchinson & McAvoy. Improved apparatus for carbureting air.
61,887. Feb. 5, 1867. Spence. Improved gas apparatus.
63,667. Apr. 9, 1867. Stevens. Improved machine for carbureting air to produce inflammable gas.
64,382. Apr. 30, 1867. Thompson. Improved gas generator and carburetor.
76,114. Mar. 31, 1868. Stratton. Improved apparatus for carbureting air.
76,182. Mar. 31, 1868. Ganster. Improved apparatus for generating illuminating gas.
78,870. June 16, 1868. Ganster. Improvement in the manufacture of illuminating gas.
81,232. Aug. 18, 1868. Van der Weyde. Improved apparatus for the manufacture of illuminating gas.
81,736. Sept. 1, 1868. Bassett. Improved process and materials for carbureting gases.
82,786. Oct. 6, 1868. Bancroft. Improved gas machine.
84,941. Dec. 15, 1868. Foster & Ganster. Improved portable gas apparatus.
85,104. Dec. 22, 1868. Lawler & Gibson. Improved gas machine.
87,299. Feb. 23, 1869. Schwippel. Improved machine for making gas from volatile oils.
90,259. May 18, 1869. Hare. Improved gas machine.

84. Nov. 30, 1869. Dunderdale. Improved apparatus for producing illuminating gas.
080. Feb. 22, 1870. Snodgrass. Improved portable gas generator.
036. May 17, 1870. Fogarty. Improved gas generator.
126. June 14, 1870. Douglas. Improved hydrocarbon vapor machine for illuminating purposes.
937. Nov. 1, 1870. Richard. Improvement in gas apparatus.
568. Nov. 22, 1870. Van Houten. Improvement in gas machine.
824. Nov. 14, 1871. McMillen. Improvement in gas machines.
025. Oct. 8, 1872. Rigod. Improvement in carburetors.
020. Jan. 21, 1873. Van Houten. Improvement in machines for carbureting air.
392. May 26, 1874. Horning. Improvement in carburetors.
564. July 13, 1875. Gray & Lusby. Improvement in air carburetors.
427. Aug. 3, 1875. Stombs. Improvement in automatic rotary carburetors.
,811. Sept. 14, 1875. Westcott. Improvement in carburetors.
,105. Oct. 26, 1875. Hyams. Improvement in carburetors.
,598. Sept. 26, 1876. Pierce. Improvement in carburetors.
7,667. Feb. 20, 1877. Paquette. Improvement in carburetors.
96,946. Nov. 6, 1877. Stratton. Improvement in carburetors.
98,270. Dec. 18, 1877. Bossert. Improvement in carburetors.
216,879. June 24, 1879. Moffatt. Improvement in air-carbureting apparatus.
223,582. Jan. 13, 1880. Dewitt. Carburetor.
226,581. Apr. 13, 1880. Wright. Carburetor.
244,387. July 19, 1881. Hoard & Wiggin. Apparatus for carbureting gas or air.
249,163. Nov. 8, 1881. De Witt. Rotary carburetor.
251,329. Dec. 20, 1881. Winn. Carburetor cylinder for air-gas machines.
262,651. Aug. 15, 1882. De Witt. Carburetor.
262,991. Aug. 22, 1882. Smith et al. Carburetor.
264,406. Sept. 12, 1882. Frail. Carbureting apparatus.
272,002. Feb. 6, 1883. Vigreux. Apparatus for producing currents of pure or carbureted air.
321,959. July 14, 1885. Frail. Gas machine.
329,664. Nov. 3, 1885. McNett. Carburetor.
350,382. Oct. 5, 1885. Merritt. Carburetor.
356,071. Jan. 11, 1887. Hyams. Apparatus for treatment of natural gas.
356,950. Feb. 1, 1887. McNett. Carburetor.
360,240. Mar. 29, 1887. Ordonez y Ponce. Gas generator.
395,616. Jan. 1, 1889. Dykes. Carburetor.
531,780. Jan. 1, 1895. Cook. Carburetor.
539,773. May 21, 1895. Lawrence. Carburetor.
593,284. Nov. 9, 1897. Spacke. Carbureter.
596,321. Dec. 28, 1897. Bulley. Gas-generating machine.
604,948. May 31, 1898. Van Vriesland. Carburetor.
618,002. Jan. 17, 1899. Bradley. Carburetor.
631,002. Aug. 15, 1899. Van Vriesland. Carburetor.
649,865. May 15, 1900. Herhagen & Van Gink. Carburetor.
672,507. Apr. 23, 1901. Johnson. Carburetor.
688,408. Dec. 10, 1901. Göhler. Carburetor.
696,187. Mar. 22, 1902. Page & Wood. Oil atomizer and mixer for vapor engines.
711,429. Oct. 14, 1902. Leckband. Carburetor.
743,085. Nov. 3, 1903. Kahle. Carbureting apparatus.
779,906. Jan. 10, 1905. Burch. Carburetor.
801,606. Oct. 10, 1905. Picard. Carbureted-air machine.
866,115. Sept. 17, 1907. Dock. Vaporizer.
885,905. Apr. 28, 1908. Averell. Carburetor.
901,237. Oct. 13, 1908. Graumüller. Carburetor.
934,981. Sept. 21, 1909. Munger. Carburetor.
942,181. Dec. 7, 1909. McGuire & Hammick. Carburetor.
969,941. Sept. 13, 1910. Cox. Carburetor.
1,009,629. Nov. 21, 1911. Bardill. Carburetor.
1,144,477. June 29, 1913. Kellogg. Carburetor.
1,156,716. Oct. 12, 1915. Shores. Carburetor.

Re. 1,819 (9,967). Aug. 30, 1853. Drake. Benzol-vapor apparatus.
Re. 2,069 (45,456). Sept. 5, 1864. McAvoy & Hutchinson. Improved apparatus for carbureting air.

Cross-reference patents, class 48, subclass 165.

56,116	82,244	153,876	692,860	840,708	1,123,876	1,137,535
57,940	138,409	189,490	754,774	1,064,273	1,137,238	

SUBCLASS 166, CARBURETORS, SUBMERGED BLAST.

43,948. Aug. 23, 1864. McAvoy. Improvement in apparatus for carbureting air.
45,206. Nov. 22, 1864. McAvoy. Improved apparatus for carbureting air.
45,568. Dec. 20, 1864. Stevens. Improved apparatus for vaporizing and aerating volatile hydrocarbon.
46,280. Feb. 7, 1865. Terry. Improved apparatus for carbureting air.
47,272. Apr. 18, 1865. Bassett. Improved apparatus for carbureting air.
47,679. May 9, 1865. Dunscomb. Improved apparatus for carbureting air.
51,128. Nov. 28, 1865. Bickford. Improved apparatus for carbureting air.
52,876. Feb. 27, 1866. Myer. Improved machine for charging air with hydrocarbon vapors.
53,843. Apr. 10, 1866. Loveless. Improved apparatus for carbureting air.
57,738. Sept. 4, 1866. Lipps. Improved barrel for petroleum, etc.
58,471. Oct. 2, 1866. Patterson. Improved apparatus for carbureting air, etc.
58,727. Oct. 9, 1866. Hutchinson. Improved apparatus for generating steam.
59,446. Nov. 6, 1866. Pease. Improvement in carburetors.
62,363. Feb. 26, 1867. Rand. Improvement in the manufacture of illuminating gas.
62,364. Feb. 26, 1867. Rand. Improvement in apparatus for carbureting air.
66,041. June 25, 1867. Rand. Improved method of making illuminating gas.
66,749. July 16, 1867. Springer & McDonald. Improved apparatus for carbureting air.
67,971. Aug. 20, 1867. Fraser. Improved carbureting apparatus.
74,132. Feb. 4, 1868. Prichard. Improvement in gas machines.
75,468. Mar. 10, 1868. Sangster. Improvement in machines for carbureting air.
75,469. Mar. 10, 1868. Sangster. Improved machine for carbureting air.
79,048. June 23, 1868. Appleby. Improved carburetor.
79,290. June 23, 1868. Willoughby. Improved carburetor.
80,404. July 28, 1868. Graham. Improved gas machine.
83,344. Oct. 20, 1868. Wain. Improved gas machine.
83,419. Oct. 27, 1868. Stebbins. Improved portable gas apparatus.
84,283. Nov. 24, 1868. Kitchen. Improved portable gas apparatus.
90,012. May 11, 1869. Mix. Improved carburetor.
95,412. Oct. 5, 1869. Barbarin. Improved apparatus for carbureting air and gas.
96,074. Oct. 26, 1869. Barbarin. Improved apparatus for carbureting air.
97,285. Nov. 30, 1869. Eberts & Fanning. Improved gas machine for carbureting air.
98,462. Jan. 4, 1870. Ball. Improved gas machine.
128,199. June 18, 1872. Gearing. Improvement in apparatus for the manufacture of gas from oils.
146,082. Dec. 30, 1873. Lyman. Improvement in carburetors.
150,449. May 5, 1874. Wheeler. Improvement in gas machines or carburetors.
155,096. Sept. 15, 1874. McHenry. Improvement in carburetors.
155,155. Sept. 22, 1874. Harrington. Improvement in carburetors.
157,781. Dec. 15, 1874. Bean. Improvement in carbureters for gas and air.
157,861. Dec. 15, 1874. Needles. Improvement in air-carbureting gas machines.
164,558. June 15, 1875. Henderson. Improvement in carburetors.
165,050. June 29, 1875. Allen. Improvement in carburetors.
165,862. July 20, 1875. Pierce. Improvement in carburetors.
166,508. Aug. 10, 1875. Daschbach. Improvement in carburetors.
173,933. Feb. 22, 1876. Forbes. Improvement in carburetors.
174,054. Feb. 29, 1876. Allen. Improvement in carburetors.

180,859. July 25, 1876. McMillen & Minor. Improvement in carburetors.
181,926. Sept. 5, 1876. Edgar. Improvement in carburetors.
193,007. July 10, 1877. Lamb. Apparatus for carbureting air.
194,733. Aug. 28, 1877. Shepard. Improvement in carburetors.
199,246. Jan. 15, 1878. Wolle & Munyon. Improvement in apparatus for carbureting air.
203,579. May 14, 1878. Battey. Improvement in carburetors.
261,507. July 18, 1882. Wittamer. Apparatus for the manufacture of illuminating gas.
273,852. Mar. 13, 1883. Judd. Gas machine.
280,201. June 26, 1883. Martin. Apparatus for the manufacture of air gas.
298,058. May 6, 1884. Beebe. Carburetor.
302,450. July 22, 1884. Valentine. Apparatus for carbureting and firing furnaces.
307,042. Oct. 21, 1884. Herzog. Process of and apparatus for obtaining illuminating gas.
327,981. Oct. 13, 1885. Andrus. Carburetor.
339,177. Apr. 6, 1886. Herlehy & McGinnis. Natural-gas carburetor.
362,234. May 3, 1887. Stauber. Gas machine.
376,248. Jan. 10, 1888. Lothammer. Carburetor.
377,607. Feb. 7, 1888. Foster. Carburetor.
382,585. May 8, 1888. Benz. Carburetor.
414,370. Nov. 5, 1889. Blackmore. Tinner's soldering apparatus.
415,978. Nov. 26, 1889. Regan. Carburetor for gas engines.
437,454. Sept. 30, 1890. Ranney. Carburetor.
474,838. May 17, 1892. Lambert. Carburetor.
484,949. Oct. 25, 1892. Clingman. Carburetor.
488,881. Dec. 27, 1892. Falley. Carburetor.
490,972. Jan. 31, 1893. Love. Apparatus for carbureting gas or air.
493,165. Mar. 7, 1893. Irgens. Apparatus for carbureting air.
504,137. Aug. 29, 1893. Savill. Carburetor.
505,700. Sept. 26, 1893. Cornish. Process of and apparatus for carbureting air.
511,950. Jan. 2, 1894. Hibbs. Process of and apparatus for carbureting air.
527,085. Oct. 9, 1894. Sprague & Guthrie. Carburetor.
527,639. Oct. 16, 1894. Westcott. Carburetor.
544,945. Aug. 20, 1895. Aldrich. Apparatus for carbureting air.
559,341. Apr. 28, 1896. Parr & Avery. Carburetor.
568,672. Sept. 29, 1896. Garred. Machine for generating gas.
569,198. Oct. 13, 1896. Henlein. Incandescent oil lighting.
569,460. Oct. 13, 1896. Ingraham. Carburetor.
572,837. Dec. 8, 1896. Staede. Carburetor.
575,595. Jan. 19, 1897. Cornish. Carburetor.
578,847. Mar. 9, 1897. Mitchell. Gas-generating machine.
588,200. Aug. 17, 1897. Van Syke. Blowpipe.
592,579. Oct. 26, 1897. Balkam. Carburetor.
593,682. Nov. 16, 1897. Oliver. Gas machine.
598,393. Feb. 1, 1898. Sams. Gas generator.
600,221. Mar. 8, 1898. Grey. Apparatus for making gas.
607,417. July 19, 1898. Bailey. Process of and apparatus for treating crude oil in manufacturing gas and lubricating oil.
610,159. Aug. 30, 1898. Speer. Carburetor.
615,093. Nov. 29, 1898. McIntyre. Internal separator.
619,281. Feb. 14, 1899. Cornish. Carburetor.
620,595. Mar. 7, 1899. Lippitt. Carburetor.
620,646. Mar. 7, 1899. Filley. Carburetor.
628,639. July 11, 1899. Steele. Carburetor.
639,481. Dec. 19, 1899. Wopert. Carburetor.
643,206. Feb. 13, 1900. Russell. Carburetor.
645,485. Mar. 13, 1900. McAllister. Carburetor.
654,878. July 24, 1900. Barckdall. Carburetor.
656,409. Aug. 21, 1900. Laraway & Houser. Carburetor.
659,987. Oct. 16, 1900. Ray. Carburetor for explosive engines.
662,304. Nov. 20, 1900. Reenstierna. Carburetor.
664,457. Dec. 25, 1900. Bennett. Carburetor.
671,042. Apr. 2, 1901. Barckdall & Woodward. Carburetor.

673,798. May 7, 1901. Kempshall. Carburetor.
673,799. May 7, 1901. Reenstierna. Carburetor.
676,054. June 11, 1901. Thomas. Carburetor.
677,305. June 25, 1901. Arnold. Carburetor.
679,019. July 23, 1901. Fischer. Carburetor.
688,814. Dec. 17, 1901. Andreson. Carburetor.
698,953. Apr. 29, 1902. Honts. Carburetor.
704,034. July 8, 1902. Head & Dovey. Carburetor.
707,973. Aug. 26, 1902. Leckband. Carburetor.
710,646. Oct. 7, 1902. Williams. Carburetor.
718,361. Jan. 13, 1903. Leckband. Apparatus for carbureting air.
723,487. Mar. 24, 1903. Richards. Carbureting device for explosive engines.
725,866. Apr. 14, 1903. Renstrom. Acetylene-gas generator.
749,315. Jan. 12, 1904. Mooers. Carbureting device for explosive engines.
750,433. Jan. 26, 1904. Cornish. Carburetor.
755,167. Mar. 22, 1904. Philipps. Carburetor.
757,935. Apr. 19, 1904. Lockhart. Carburetor.
777,908. Dec. 20, 1904. Lothammer. Carburetor.
781,701. Feb. 7, 1905. Walther. Carburetor.
782,788. Feb. 14, 1905. Mohr. Carburetor.
793,786. July 4, 1905. Helmle. Carburetor.
805,138. Nov. 21, 1905. Herrick & Lohrman. Carburetor.
812,753. Feb. 13, 1906. Kouns. Carburetor for hydrocarbon engines.
817,218. Apr. 10, 1906. Brown. Carburetor.
823,382. June 12, 1906. Akeson. Carburetor.
826,936. July 24, 1906. Hinds. Carburetor.
829,375. Aug. 21, 1906. Garvey. Air carburetor.
840,115. Jan. 1, 1907. Dawson. Gas generator.
862,196. Aug. 6, 1907. Peregrine. Carburetor.
913,733. Mar. 2, 1909. Kenworthy. Gas generator.
920,511. May 4, 1909. Wood. Carburetor.
932,478. Aug. 31, 1909. Laux. Carburetor.
932,871. Aug. 31, 1909. Kenworthy. Carburetor.
938,011. Oct. 26, 1909. Miéville. Carburetor.
947,357. Jan. 25, 1910. Steward. Carburetor.
950,825. Mar. 1, 1910. Pill. Carbureting apparatus.
951,501. Mar. 8, 1910. Hancock & Arnold. Gas generator.
956,048. Apr. 26, 1910. Dawson. Carbureting apparatus.
965,867. Aug. 2, 1910. Bustard. Carburetor.
988,398. Apr. 4, 1911. Stein. Carburetor.
989,848. Apr. 18, 1911. Kemp. Carburetor.
989,980. Apr. 18, 1911. Kemp. Carburetor.
994,574. June 6, 1911. Cox. Carburetor.
995,882. June 20, 1911. Lowry. Hydrocarbon lighting system.
1,002,791. Sept. 5, 1911. Voigt. Carburetor.
1,004,329. Sept. 26, 1911. Winter. Carbureting apparatus.
1,009,121. Nov. 21, 1911. Weiwoda. Carburetor.
1,027,840. May 21, 1912. Johnston. Carburetor.
1,027,456. May 28, 1912. Wood. Carburetor.
1,043,691. Nov. 5, 1912. Grandjean. Carburetor.
1,057,254. Mar. 25, 1913. McAndrews. Carburetor.
1,058,407. Apr. 8, 1913. Candlish. Carburetor.
1,069,068. July 29, 1913. Kemp. Carbureter.
1,069,335. Aug. 5, 1913. Johnson. Carburetor.
1,070,394. Aug. 19, 1913. Booth. Carburetor.
1,103,789. July 14, 1914. Macey. Carburetor.
1,105,160. July 28, 1914. Sanders. Carburetor.
1,109,777. Sept. 8, 1914. Müller. Carburetor.
1,156,924. Oct. 19, 1915. Nichols. Carburetor.
Re. 3,892 (95,412). Mar. 22, 1870. Barbarin. Improvement in apparatus for carbureting air and gas.
Re. 6,376 (67,971). Apr. 13, 1875. Fraser. Improvement in carbureting apparatus.
Re. 6,431 (51,128). May 18, 1875. Bickford. Improvement in apparatus for carbureting air.
Re. 13,498. Dec. 17, 1912. Bustard. Carburetor.
1,191,097. July 11, 1916. Spiers. Carbuetor.

Cross-reference patents, class 48, subclass 166.

8,433	107,853	188,667	512,270	646,320	706,454	906,548
32,222	110,946	221,942	515,440	654,686	707,467	912,468
38,357	116,563	233,978	518,582	657,770	707,897	929,135
42,469	117,998	306,485	522,418	658,020	716,227	931,386
55,395	125,194	307,132	Re. 11,430	659,476	745,489	941,393
57,551	127,031	311,493	554,630	663,683	749,768	953,606
63,511	130,164	324,177	566,413	673,365	762,477	940,916
66,545	138,160	356,477	566,415	674,812	772,551	947,639
66,777	142,545	360,944	576,499	679,018	784,599	951,590
67,216	150,827	370,936	586,923	688,776	817,218	1,005,491
76,535	151,557	403,839	603,431	689,460	828,334	1,014,133
78,600	156,463	411,809	607,888	690,303	836,795	1,044,594
80,268	164,825	422,322	607,889	690,681	844,995	1,062,273
82,359	167,170	435,856	613,167	692,255	853,196	1,065,819
96,073	175,827	457,803	625,294	697,807	860,522	1,091,784
97,283	176,955	484,721	629,246	702,637	871,480	1,095,510
105,190	178,978	493,992	639,336	705,021	887,017	1,107,489

SUBCLASS 167, CARBURETORS, SUBMERGED BLAST, COIL.

50,029. Sept. 29, 1865. Pond & Richardson. Improved apparatus for carbureting air.
114,316. May 2, 1871. Marks. Improvement in carburetors for air and gas.
200,568. Feb. 19, 1878. Reed. Improvement in carburetors.
290,491. Dec. 18, 1883. Snell. Means for facilitating the passage of oil through pipes and making illuminating gas.
308,796. Dec. 2, 1884. Ransom. Gas machine.
314,412. Mar. 24, 1885. Allender. Hydrocarbon-gas machine.
451,218. Apr. 28, 1891. Bradley. Grass burner for railway tracks
502,781. Aug. 8, 1893. Smith. Carburetor.
615,100. Nov. 29, 1898. Parrott. Carburetor.
632,376. Sept. 5, 1899. Stanley. Carburetor.
762,271. June 14, 1904. Bennett & Moorwood. Carburetor for motor cars.
773,822. Oct. 25, 1904. Hinman. Carburetor.
848,933. Apr. 2, 1907. Thiem. Carburetor.
865,060. Sept. 3, 1907. Rockwell. Carburetor.
895,273. Aug. 4, 1908. Keitel. Carbureting apparatus.

Cross-reference patents, class 48, subclass 167.

53,481	168,290	275,268	622,489	640,695	795,233	1,002,791
67,576	272,848	596,536				

SUBCLASS 168, CARBURETORS, SURFACE.

24,200. May 31, 1859. Covel. Hydrocarbon-vapor apparatus.
27,470. Mar. 13, 1860. Pease. Hydrocarbon-vapor apparatus.
46,302. Feb. 7, 1865. McAvoy. Improved apparatus for carbureting air.
47,256. Apr. 11, 1865. Irwin. Improved apparatus for carbureting air.
47,550. May 2, 1865. Hurd. Improved apparatus for carbureting air.
53,979. Apr. 17, 1866. Hogan. Improved apparatus for carbureting gas.
58,559. Oct. 2, 1866. Stevens. Improved apparatus for carbureting air.
61,004. Jan. 8, 1867. Gilbert et al. Improvement in apparatus for carbureting air.
61,656. Jan. 20, 1867. Douglas & Walton. Improved apparatus for carbureting air.
64,156. Apr. 23, 1867. Simonds. Improved apparatus for carbureting air.
69,037. Sept. 17, 1867. Spence. Improved hydrocarbon-vapor machine.
70,809. Nov. 12, 1867. Cozzens & Jones. Improved apparatus for carbureting air.
89,665. May 5, 1869. H. Johnson. Improved apparatus for carbureting air or gas.
91,213. June 15, 1869. Covel. Improved carburetor.
93,288. Aug. 3, 1869. Dyer. Improved gas carburetor.

96,364. Nov. 2, 1869. Tiffany. Improved apparatus for carbureting and applying air for lighting and heating.
99,274. Jan. 25, 1870. Spence & Towsley. Improved apparatus for carbureting air.
105,378. July 12, 1870. Simonds. Improvement in carbureting apparatus.
105,994. Aug. 2, 1870. Spence. Improvement in apparatus for carbureting air.
114,709. May 9, 1871. Rex. Improvement in apparatus for carbureting air.
114,787. May 16, 1871. Fitts. Improvement in apparatus for carbureting air.
125,085. Mar. 26, 1872. Reznor. Improved apparatus for carbureting air.
151,153. May 19, 1874. Palmer. Improvement in carburetors.
160,799. Mar. 16, 1875. Vougt. Improvement in apparatus for the production of gas from hydrocarbon liquid.
174,073. Feb. 29, 1876. Gray. Improvement in carburetors.
183,884. Oct. 31, 1876. Bangs. Improvement in gas carburetors.
219,158. Sept. 2, 1879. Jackson. Improvement in carburetors.
234,055. Nov. 2, 1880. Ormsby. Carbureting apparatus.
234,108. Nov. 2, 1880. Ruthven. Carbureting apparatus.
238,141. Feb. 22, 1881. McKensie & Mason. Carburetor.
245,443. Aug. 9, 1881. Callahan. Carburetor.
288,952. Nov. 20, 1883. Müller. Combined gas engine and carbureting apparatus.
302,442. July 22, 1884. Strong. Carburetor.
333,508. Jan. 5, 1886. English. Carburetor.
347,663. Aug. 17, 1886. Tibbets. Apparatus for carburetor gas.
409,570. Aug. 20, 1889. Elder. Carburetor.
433,336. July 29, 1890. Fiesse. Apparatus for oxygenating and carbureting air.
545,048. Aug. 27, 1895. Brunner. Carburetor.
545,125. Aug. 27, 1895. Grist. Vaporizer for gas motors.
614,400. Nov. 15, 1898. Lee et al. Composition, process of, and apparatus for making gas.
670,433. Mar. 28, 1901. Powers. Carburetor.
671,375. Apr. 2, 1901. Gallaher. Carburetor.
677,767. July 2, 1901. Jeffery. Hydrocarbon spraying device for gasoline engines.
682,905. Sept. 17, 1901. Bland. Vaporizer for explosive engines.
*683,110. Sept. 24, 1901. Felbaum. Mixing and vaporizing device for explosive engines.
693,462. Feb. 18, 1902. Titus. Combined carburetor and gasoline regulator.
727,635. May 12, 1903. Jeffery. Carburetor.
742,452. Oct. 27, 1903. De Laitte. Carburetor.
758,902. May 3, 1904. Dickinson. Vaporizer for explosive engines.
774,798. Nov. 15, 1904. Thompson. Carburetor.
*775,614. Nov. 22, 1904. Swain. Carburetor for explosive engines.
777,390. Dec. 13, 1904. O'Shea. Carburetor.
790,025. May 16, 1906. Bennett. Air carburetor.
792,158. June 13, 1905. Olds. Vaporizing device for explosive engines.
*837,984. Dec. 11, 1906. Vail. Vaporizer for internal-combustion engines.
853,915. May 14, 1907. Bowles et al. Apparatus for extracting gas from gasoline.
*857,111. June 18, 1907. Rice. Vaporizer for gas engines.
872,505. Dec. 3, 1907. Gore. Carburetor.
*886,283. Apr. 28, 1908. Wayrynen. Carburetor.
915,132. Mar. 16, 1909. Warstler. Carburetor.
916,463. Mar. 30, 1909. Looby. Carburetor.
*917,264. Apr. 6, 1909. De Thay. Carburetor.
951,923. Mar. 15, 1910. Van Buren. Carburetor.
957,731. May 10, 1910. Brady. Carburetor.
961,423. June 14, 1910. Sturtevant. Carburetor.
975,038. Nov. 8, 1910. Hockman. Carburetor.
979,907. Dec. 27, 1910. White. Carburetor.
1,108,081. Aug. 18, 1914. Oliver. Carbureting apparatus.
*1,110,453. Sept. 15, 1914. Monosmith. Carburetor.
1,136,997. Apr. 27, 1915. Bennett. Carburetor.
*1,141,796. June 1, 1915. Hertzog. Carburetor.
1,146,441. July 13, 1915. Oliver. Carbureting apparatus.

,183,864. May 23, 1916. Gardner. Carburetor.
e. 2,893 (27,470). Mar. 10, 1868. Pease. Hydrocarbon vapor apparatus.
e. 3,225 (46,302). Dec. 8, 1868. Mix. Improved apparatus for carbureting air.
e. 6,754 (91,213). Nov. 23, 1875. Austin. Improvement in automatic feed and absorption carburetors.

Cross-reference patents, class 48, subclass 168.

24,199	79,667	162,848	226,122	587,867	772,530	990,159
47,986	83,147	163,323	238,818	620,496	876,678	1,050,322
50,250	84,234	176,349	248,750	620,586	885,230	1,109,085
52,946	103,994	184,049	261,861	622,008	964,657	1,123,469
55,950	104,642	189,727	308,886	672,854	951,501	1,125,368
63,215	111,175	190,714	311,858	701,890	973,882	1,157,363
64,776	127,039	193,407	312,289	706,600	976,322	
65,705	Re. 5,465	194,121	353,311	720,336	976,781	
66,067	149,111	199,928	379,129	738,604	976,885	
66,071	153,538	203,458	390,037	737,738	989,697	
70,014	Re. 6,070	211,194	427,225	742,920	989,848	
72,825	160,690	213,351	500,772	749,768	990,848	

SUBCLASS 169, CARBURETORS, SURFACE, FLOAT.

,549. June 5, 1860. Ashcroft. Apparatus for naphthalizing gases.
,883. Nov. 1, 1864. Odiorne. Improved apparatus for carbureting air.
,473. Nov. 6, 1866. Stevens. Improved apparatus for carbureting air.
,991. Nov. 27, 1866. Frank. Improved apparatus for carbureting air.
,918. Feb. 12, 1867. Pierce. Improved apparatus for carbureting gas.
,937. July 23, 1867. Pierce. Improved apparatus for carbureting gas.
,483. Oct. 1, 1867. Richardson & Pond. Improvement in generating gas from hydrocarbon liquids.
,665. Dec. 3, 1867. Thompson & Hall. Improved carbureting apparatus.
,073. Jan. 7, 1868. Bierce. Improved apparatus for carbureting.
,239. Oct. 20, 1868. Bassett. Improved apparatus for the manufacture of illuminating gas.
,332. Nov. 24, 1868. Wood. Improved apparatus for carbureting air.
,192. Feb. 23, 1869. Paine. Improved apparatus for charging air with hydrocarbon vapors.
4,716. June 28, 1870. Dupas & Barbarin. Improvement in apparatus for carbureting air.
5,190. July 12, 1870. Galagher. Improvement in gas machines.
3,147. Mar. 28, 1871. Dupas & Barbarin. Improvement in carbureting machines.
5,684. June 6, 1871. Bloomfield. Improvement in the manufacture of pneumatic gas.
3,302. Aug. 22, 1871. Tirrill. Improvement in apparatus for carbureting air and gas.
1,210. Sept. 10, 1872. Butler. Improvement in carbureting attachments for gas burners.
1,369. Sept. 17, 1872. Ofeldt. Improvement in carburetors.
1,943. Oct. 8, 1872. Dayton. Improvement in carburetors for air and gas.
3,228. Feb. 28, 1873. Elston. Improvement in carburetors.
1,968. Aug. 19, 1873. Van Houten. Improvement in apparatus for carbureting air.
3,523. Oct. 7, 1873. McMillan. Improvement in carburetors.
1,858. Nov. 23, 1873. Musgrave. Improvement in carburetors.
3,313. Jan. 13, 1874. Carr. Improvement in carburetors.
7,256. Feb. 10, 1874. Gray. Improvement in carburetors.
2,523. Apr. 27, 1875. Bickford. Improvement in carburetors.
2,543. Apr. 27, 1875. Foster. Improvement in carbureting gas machines.
,751. Jan. 4, 1876. Wiggin. Improvement in carburetors.
3,973. Jan. 20, 1876. Stewart. Improvement in carburetors.
2,345. Sept. 19, 1876. Bickford. Improvement in carouretors.
9,419. May 8, 1877. Clingman. Improvement in floats for carburetors.
3,304. Oct. 23, 1877. Meredith. Improvement in carburetors.

211,176. Jan. 7, 1879. Ofeldt. Improvement in carburetors.
223,763. Jan. 20, 1880. Sanders. Carbureting apparatus.
225,435. Mar. 9, 1880. Strong. Apparatus for enriching and economizing coal gas.
227,853. May 18, 1880. Soule. Carburetor.
230,656. Aug. 3, 1880. Radkey. Carburetor.
244,434. July 19, 1881. Clingman. Carburetor.
251,673. Dec. 27, 1881. Barry. Carburetor.
254,243. Feb. 28, 1882. Small. Carburetor.
306,331. Oct. 7, 1884. Gardner et al. Gas machine.
306,485. Oct. 14, 1884. Hartfeldt. Gas generator.
309,467. Dec. 16, 1884. James. Apparatus for enriching coal gas.
355,594. Jan. 4, 1887. Daimler. Apparatus for impregnating air with hydrocarbon vapor.
362,197. May 3, 1887. Bennett. Carbureting apparatus.
370,149. Sept. 20, 1887. Leede. Carburetor.
371,034. Oct. 4, 1887. Collins. Carburetor.
423,257. Mar. 11, 1890. Huber. Carburetor.
433,495. Aug. 5, 1890. Smith. Carburetor.
475,972. May 31, 1892. Badlam. Carburetor.
528,377. Oct. 30, 1894. Moncur. Carburetor.
543,611. July 30, 1895. Clingman. Carburetor.
546,815. Sept. 24, 1895. Hain. Carburetor.
557,086. Mar. 24, 1895. Schroeder. Gas enricher.
562,214. June 16, 1896. Burrows. Vapor-gas apparatus.
596,560. Jan. 4, 1898. Welch. Process of and apparatus for generating gas.
608,531. Aug. 2, 1898. Stephenson. Carburetor.
622,808. Apr. 11, 1899. Kemp. Carburetor.
629,581. July 25, 1899. Martenette. Carburetor.
638,557. Dec. 5, 1899. Cary. Carburetor.
642,187. Jan. 30, 1900. Welch. Carbureting apparatus.
643,397. Feb. 13, 1900. Broichgans. Carburetor.
649,435. May 15, 1900. Carter & Zierlein. Carburetor.
653,534. July 10, 1900. Shearer. Carburetor.
656,495. Aug. 21, 1900. Anderson. Carburetor.
659,438. Oct. 9, 1900. Egan. Carburetor.
665,743. Jan. 8, 1901. Kern. Carburetor.
669,157. Mar. 5, 1901. Carter & Zierlein. Carburetor.
708,826. Sept. 9, 1902. Paul & Gundlack. Carburetor.
712,150. Oct. 28, 1902. Parrett. Carburetor.
733,498. July 14, 1903. Maurer. Carburetor.
742,533. Oct. 27, 1903. Walther. Carburetor.
744,877. Nov. 24, 1903. Parrott. Carburetor.
773,231. Oct. 25, 1904. Smith. Carburetor.
776,542. Dec. 6, 1904. Paul. Carburetor.
782,980. Feb. 21, 1905. Moehn. Carbureting apparatus.
816,267. Mar. 27, 1906. Steel. Carbureting apparatus.
819,074. May 1, 1906. Monroe. Gas-generating machine.
887,230. May 12, 1908. Rife. Carburetor.
951,590. Mar. 8, 1910. Brown. Carburetor.
1,049,273. Dec. 31, 1912. Ruthven. Carburetor.
1,055,891. Mar. 11, 1913. Doudney. Carbureting apparatus.
1,064,102. June 10, 1913. Smith & Keiver. Carburetor.
1,141,276. June 1, 1915. Smith. Carburetor.
1,155,184. Sept. 28, 1915. Winger. Carburetor.
Re. 1,024 (28,549). Aug. 14, 1860. Ashcroft. Improvement in apparatus for naphthalizing gases.
Re. 2,253 (44,883). May 22, 1866. Odiorne. Improved apparatus for carbureting air.

Cross-reference patents, class 48, subclass 169.

149,060	317,197	661,660	886,403	947,639	950,825	1,113,892
267,933	317,686	797,615	940,916			

SUBCLASS 219, PROCESSES, CARBURETING.

8,017. Mar. 24, 1868. Simonds & Warner. Improvement in treating gas for illumination.
0,385. Oct. 10, 1865. Pond. Improvement in the manufacture of illuminating gas.
0,491. Oct. 17, 1865. Pond. Improved apparatus for carbureting air.
5,359. June 5, 1866. Pond & Richardson. Improvement in generating and supplying illuminating gas.
6,070. June 25, 1867. Bassett. Improvement in the manufacture of illuminating gas.
7,796. Aug. 13, 1867. Pedrick. Improved process for treating petroleum.
00,534. Mar. 8, 1870. Lawrence. Improvement in carbureting air.
07,268. Sept. 13, 1870. Kidder. Improvement in carbureting apparatus.
10,427. Dec. 27, 1870. Boynton. Improvement in the methods of producing illuminating gas.
28,357. June 1, 1880. Jackson. Process of carbureting gas and air.
77,735. Feb. 14, 1888. Bidelman. Process of carbureting air.
20,797. Feb. 4, 1890. Hollingsworth. Process of vaporizing liquid hydrocarbons and supplying the vapor to burners.
25,877. Apr. 15, 1890. Hanford. Process of carbureting air or gas.
67,266. Jan. 19, 1892. Stringfellow. Process of manufacturing gas.
83,489. Sept. 27, 1892. Bidelman. Manufacture of gas.
87,617. Dec. 6, 1892. Griffes & Clarke. Process of carbureting air.
99,483. June 13, 1893. Tatham. Method of making gas.
79,415. Mar. 23, 1897. Van Norman. Manufacture of carbureted-air gas.
84,349. June 15, 1897. Griffen. Process of carbureting gas.
45,425. Mar. 13, 1900. McAllister. Process of carbureting.
56,484. Aug. 21, 1900. Shearer. Process of carbureting air or gas.
78,973. July 23, 1901. North. Process of making carbureted air.
21,957. Mar. 3, 1903. Kuenzel. Process of producing combustible fluid.
49,767. Jan. 19, 1904. Wilson. Process of producing carbureted air.
55,094. May 28, 1907. Busenbenz. Gas-manufacture process.
65,624. Sept. 10, 1907. Ziegler. Process for the manufacture of illuminating and heating gas.
85,095. Apr. 21, 1908. Solomon. Method of producing gas from alcohol.
78,853. Dec. 20, 1910. Cutter. Method of and apparatus for making gas.
,019,430. Mar. 5, 1912. Dawson. Method of carbureting air.
,042,567. Oct. 29, 1912. Kuenzel. Process for producing combustible gas.
,183,939. May 23, 1916. Whittelsey. Vaporizing process.

Cross-reference patents, class 48, subclass 219.

2,357	94,360	119,663	268,878	464,779	590,893	614,400
66,069	110,946	163,323	349,211	511,950	596,560	1,109,777
69,483	114,744	169,423	356,477	527,789	607,417	1,150,782
72,118	117,998	206,196				

LIST No. 2.

ROSS-REFERENCE PATENTS FROM LIST No. 1, WITH PATENTS BELONGING IN, OR REGULARLY ASSIGNED TO, THE SUBCLASSES OF LIST No. 1 OMITTED.

,433. Oct. 14, 1851. Warner. Lamp for burning vapor of benzol, etc.
,967. Aug. 30, 1853. Drake. Benzol vapor apparatus.
1,720. Mar. 19, 1861. Kendall. Apparatus for naphthalizing gas.
2,222. Apr. 30, 1861. Gwynne. Apparatus for naphthalizing gas.
5,984. July 29, 1862. Bassett. Improvement in apparatus for carbureting gas.
6,770. Mar. 14, 1865. Bassett. Improvement of burners for carbureted air.
7,986. May 30, 1865. Salisbury. Improved apparatus for the manufacture of gas.
6,116. July 3, 1866. Stevens. Improvement in treating gas for illumination and other purposes.
2,856. Mar. 12, 1867. Kidd. Carburetor.

70,014. Oct. 22, 1867. Pease. Improved carburetor for locomotive headlights.
72,118. Dec. 10, 1867. Terry. Improvement in manufacturing illuminating gas.
73,900. Jan. 28, 1868. Jenkins. Improved carbureted-air lamp.
76,535. Apr. 7, 1868. Sloan. Improved apparatus for generating gas.
84,234. Nov. 17, 1868. Verstraet. Improvement in hydrocarbon burners.
89,536. Apr. 27, 1869. Wood. Improvement in lamps.
90,436. May 25, 1869. Dunderdale. Improvement in carburetors.
107,743. Sept. 27, 1870. Whitney. Improvement in gas-carbonizing attachments for lights.
110,005. Dec. 13, 1870. Brown. Improvement in gaslights.
114,358. May 2, 1871. Simonds. Improvement in gas machines.
114,744. May 16, 1871. Ambuhl. Improvement in apparatus for carbureting hydrogen gas.
115,988. June 13, 1871. Sloper. Improvement in apparatus for carbureting air.
119,663. Oct. 3, 1871. Springer. Improvement in gas machines.
128,321. June 25, 1872. Myer. Improvement in apparatus for the manufacture of illuminating gas.
130,164. Aug. 6, 1872. Symes. Improvement in apparatus for the manufacture of gas.
132,132. Oct. 15, 1872. Ball. Improvement in carbureting gas lamps.
133,118. Nov. 19, 1872. Post. Improvement in carbureting lamps.
138,160. Apr. 22, 1873. Irland. Improvement in gas generators.
138,715. May 6, 1873. Tilden. Improvement in gas machine.
143,534. Oct, 7, 1873. Shaler. Improvement in carburetors.
149,060. Mar. 31, 1874. Ramsdell. Improvement in the manufacture of wood gas.
151,557. June 2, 1874. Bingham. Improvement in the manufacture of hydrogen gas.
153,952. Aug. 11, 1874. Hawes. Improvement in gas-carbureting machines.
156,172. Oct. 20, 1874. Olney. Improvement in processes and apparatus for the manufacture of illuminating gas.
163,323. May 18, 1875. Martin. Improvement in the manufacture of gas.
163,535. May 18, 1875. Shaler. Improvement in carburetors.
167,150. Aug. 31, 1875. Ball. Vapor burner.
168,910. Oct. 19, 1875. Marks. Improvement in carburetors.
177,191. May 9, 1875. Ball. Improvement in lamps.
189,727. Apr. 17, 1877. Greenough. Apparatus for producing illuminating gas.
190,673. May 15, 1877. Dopp. Improvement in hydrocarbon liquid attachments for gas burners.
191,381. May 29, 1877. Spengler. Improvement in oil-gas burners.
192,825. July 10, 1877. Hangliter. Improvement in apparatus for carbureting air.
194,121. Aug. 14, 1877. Austin. Improvement in lamps for burning naphtha gas.
197,944. Dec. 11, 1877. Palmer. Improvement in carbureting lamps.
206,999. Aug. 13, 1878. Ball. Improvement in carbureting lamps.
210,717. Dec. 10, 1878. Sloane. Improvement in carburetors for cars.
213,351. Mar. 18, 1879. Roth. Improvement in carburetors.
225,778. Mar. 23, 1880. Wittig & Hees. Gas engine.
228,547. June 8, 1880. Maxim. Gas apparatus.
238,757. Mar. 15, 1881. Brainard. Carburetor.
240,994. May 3, 1881. Gaume. Gas engine.
242,379. May 31, 1881. Dhaler. Carburetor.
249,160. Nov. 8, 1881. Crocker. Cooking apparatus.
252,307. Jan. 17, 1882. Fagan. Device for burning air and hydrocarbon vapors.
261,861. Aug. 1, 1882. Litchfield & Henshaw. Burning and carbureting air.
267,933. Nov. 21, 1882. Ramsdell. Apparatus for manufacturing wood gas.
275,238. Apr. 3, 1883. Marcus. Vaporizer.
278,281. May 28, 1883. Shaler. Carburetor.
284,373. Sept. 4, 1883. Brough. Carburetor.
286,030. Oct. 2, 1883. Marcus. Gas engine.
302,045. July 15, 1884. Spiel. Gas engine.

8,693. Dec. 2, 1884. Paquelin et al. Veterinary cauterizer.
9,835. Dec. 30, 1884. Etève & De Braam. Carbureted-air engine.
2,512. Feb. 17, 1885. Roy. Cauterizing apparatus.
7,197. May 5, 1885. Ramsdell. Apparatus for manufacturing gas from wood.
,572. Feb. 23, 1886. Leede. Automatic carbureting lamp.
,574. Feb. 23, 1886. Leede. Automatic carbureting lamp.
,211. Sept. 14, 1886. Cottrell. Method of and apparatus for carbureting and mixing gas.
,200. Oct. 5, 1886. Humee. Hydrocarbon vapor engine.
,382. Oct. 5, 1886. Merritt. Carburetor.
0,769. Oct. 12, 1886. Ragot & Smyers. Petroleum and gas motor.
,476. Jan. 25, 1887. Johnston. Process of and apparatus for manufacturing illuminating gas.
,944. Apr. 12, 1887. Averell. Process of and apparatus for generating illuminating gas.
,258. Sept. 30, 1887. Holt & Crossley. Gas motor engine.
,638. Jan. 17, 1888. Daimler. Engine-driven vehicle.
,647. Feb. 28, 1888. Bennett. Carbureting lamp.
,129. Mar. 6, 1888. Sanders. Car motor.
,121. June 26, 1886. King & Brown. Carburetor.
,029. July 10, 1888. Priestman. Motor engine operated by the combustion of liquid hydrocarbon.
3,367. May 14, 1889. Parker. Gas or gasoline engine.
1,474. Feb. 15, 1890. Beckfield & Schmid. Gas engine.
3,367. Mar. 11, 1890. Young. Carbureting street lamp.
23,393. Mar. 11, 1890. Roy. Cauterizing apparatus.
24,654. Apr. 1, 1890. McClelland et al. Vapor stove.
429,426. June 3, 1890. Dawson. Carbureting apparatus.
435,856. Sept. 2, 1890. Parker. Carburetor.
*439,813. Nov. 4, 1890. Diederichs. Vapor engine.
451,036. Apr. 28, 1891. Frost. Carburetor and attachment for lamps connected therewith.
*477,295. June 21, 1892. Charter. Gas engine.
488,454. Dec. 20, 1892. Roy. Thermocauter.
489,762. Jan. 10, 1893. Ruthven. Gas cooking apparatus.
490,415. Jan. 24, 1893. Reid et al. Lamp.
497,048. July 16, 1888. Durand. Carbureted-air engine.
500,477. June 27, 1893. Drysdale. Valve for hydrocarbon engines.
*504,723. Sept. 12, 1893. Gray. Hydrocarbon engine.
505,767. Sept. 26, 1893. Irgene. Gas or petroleum engine.
507,989. Nov. 7, 1893. Brünler. Petroleum motor.
512,270. Jan. 9, 1894. Blakeley. Apparatus for manufacturing gas.
515,440. Feb. 27, 1894. McGarrier. Carburetor.
538,791. May 7, 1895. Reichardt. Carburetor for thermocauters.
541,441. June 16, 1895. Lee. Thermocauter.
*542,043. July 2, 1895. Charter. Governor for gas engines.
542,410. July 9, 1895. Griffin. Liquid-hydrocarbon motor.
548,689. Oct. 29, 1895. Wirsching. Thermocauter.
*549,939. Nov. 19, 1895. Seck. Marine hydrocarbon motor.
*550,675. Dec. 3, 1895. Colborne. Gas or vapor engine.
552,312. Dec. 31, 1895. Battey. Motor for bicycles.
552,718. Jan. 7, 1896. Priestman. Hydrocarbon engine.
554,207. Feb. 4, 1896. Woodard. Vapor stove.
554,699. Feb. 18, 1896. Johnson. Gas generator or vaporizer.
*555,717. Mar. 3, 1896. Weinman et al. Gas engine.
555,373. Feb. 25, 1896. Henroid-Schweizer. Petroleum motor.
*557,496. Mar. 31, 1896. Duryea. Engine or motor.
562,307. June 16, 1896. Lamos. Gas engine.
*563,541. July 7, 1896. Allman. Vaporizer for oil engines.
563,548. July 7, 1896. Bodell. Gas or oil engine.
564,155. July 14, 1896. Millet. Velocipede.
564,769. July 29, 1896. Swain. Gas or oil engine.
568,017. Sept. 22, 1896. Cundall. Oil and gas motor engine.
574,614. Jan. 5, 1897. Lamos. Gas-engine attachment.
575,720. Jan. 26, 1897. Ledent. Gas engine.
582,073. May 4, 1897. Mead. Gas or oil engine.

583,982. June 8, 1897. Davis. Gasoline and gas engine.
*585,115. June 22, 1897. Miller. Gas engine.
*587,627. Aug. 3, 1897. Williams. Gas engine.
592,794. Nov. 2, 1897. Lanchester. Gas or oil motor engine.
593,034. Nov. 2, 1897. Spacke. Gas engine.
596,536. Jan. 4, 1898. Park. Combined gasoline blowpipe and burner.
602,820. Apr. 23, 1898. Beck. Gas engine.
*605,815. June 14, 1898. Duryea. Gas engine.
609,031. Aug. 30, 1898. Parker. Carburetor.
612,258. Oct. 11, 1898. Mead. Gas or oil engine.
*613,757. Nov. 8, 1898. Carnell. Gas engine.
617,530. Jan. 10, 1899. Howard. Direct conversion of energy of fuel and an expansion medium into power.
620,496. Feb. 28, 1899. Ravenèz. Carburetor.
*622,891. Apr. 11, 1899. Graef. Gas engine.
623,190. Apr. 18, 1899. Stoddard. Explosive engine.
623,361. Apr. 18, 1899. Frew. Oscillating gas or steam engine.
*625,887. May 30, 1899. Lair. Engine.
627,359. June 20, 1899. Steele. Automobile vehicle.
*627,857. June 27, 1899. Knox. Gas engine.
628,222. July 4, 1899. Hewitt. Vapor blowpipe.
*632,859. Sept. 12, 1899. Walrath. Explosive engine.
632,888. Sept. 12, 1899. Ayres. Gas engine.
633,014. Sept. 12, 1899. Lawson. Motor vehicle.
635,456. Oct. 24, 1899. Wood & Eddy. Gasoline lamp.
637,299. Nov. 21, 1899. Strong. Oil-vaporizing device for gas engines.
*645,044. Mar. 6, 1900. Otto. Gas engine.
*657,140. Sept. 4, 1900. Starr & Cogswell. Explosive gas engine.
659,911. Oct. 16, 1900. Barnard. Gas engine.
*660,482. Oct. 23, 1900. Bates. Rotary explosive engine.
662,922. Dec. 4, 1900. Dudley. Branding iron.
*664,200. Dec. 18, 1900. White. Gasoline engine.
668,952. Feb. 26, 1901. Carson. Desulphurizing coppe matte.
672,500. Apr. 23, 1901. Van Duzen. Vaporizing device for crude-oil explosive engines.
673,138. Apr. 30, 1901. Miller. Governing device for explosive engines.
*677,283. June 25, 1901. Secor. Oil-feed device for explosive motors.
679,018. July 23, 1901. Fischer. Oil feed for carburetors.
679,389. July 30, 1901. McCall. Governor for explosive engines.
*686,092. Nov. 5, 1901. Lear. Vaporizer for gasoline engines.
*686,101. Nov. 5, 1901. Maybach. Regulation device for explosion motors.
690,486. Jan. 7, 1902. Tomlinson. Apparatus for the vaporization, combustion, and utilization of hydrocarbon oils.
*690,610. Jan. 7, 1902. Richardson. Hydrocarbon engine.
692,071. Jan. 28, 1902. Pugh. Explosive engine.
692,860. Feb. 11, 1902. Kemp. Carburetor.
*696,146. Mar. 25, 1902. Riotte. Mixing or spraying device.
698,895. Apr. 29, 1902. Beck. Continuous-combustion turbine.
*703,769. July 1, 1902. De Long. Motor vehicle.
706,482. Aug. 5, 1902. Wirsching. Thermocauter.
*706,494. Aug. 5, 1902. Minogue. Motive-power engine.
*710,841. Oct. 7, 1902. Brush. Mixing valve for gas or gasoline engines.
*726,986. May 5, 1903. Peteler. Carburetor for gas engines.
*730,084. June 2, 1903. Boulfuss. Gas or vapor engine.
733,444. July 14, 1903. Washburne. Carburetor.
734,772. July 28, 1903. Strowger. Carbureting lamp.
737,738. Sept. 1, 1903. Hitchcock. Vapor generator.
*740,571. Oct. 6, 1903. Joranson. Gas engine.
745,055. Nov. 24, 1903. Harris. Explosive engine.
745,578. Dec. 1, 1903. Dean. Apparatus for supplying explosive engines with explosive mixtures.
747,190. Dec. 15, 1903. Krauss. Motor wheel for bicycles or other vehicles.
*747,264. Dec. 15, 1903. Sturtevant. Carburetor for explosion engines.
750,764. Jan. 26, 1904. Harmany. Carburetor.
753,510. Mar. 1, 1904. Murdock. Gas engine.
758,790. May 3, 1904. Snell. Carburetor.

247. May 17, 1904. Ranney. Carburetor.
732. Aug. 16, 1904. Bromley. Centralizing operating mechanism for valves.
063. Aug. 23, 1904. Maton. Carbureting lamp.
,530. Oct. 18, 1904. McGee. Carburetor for gasoline engines.
443. Nov. 1, 1904. Chace. Oil burner.
127. Apr. 25, 1905. Reichenbach. Self-carbureting lamp.
325. May 23, 1905. Stelle. Explosive engine.
,501. June 6, 1905. Richard. Gas or explosion engine.
,712. Aug. 8, 1905. Fergusson & Sheppy. Carburetor for hydrocarbon engines.
996. Oct. 3, 1905. Drummond. Internal-combustion engines.
390. Oct. 10, 1905. Low. Hydrocarbon motor.
,125. Dec. 5, 1905. Farwell. Rotary explosive engine.
460. Dec. 5, 1905. Bucklin. Spraying device.
131. Dec. 12, 1905. Sale. Carburetor.
391. Dec. 12, 1905. Low. Hydrocarbon motor.
,835. Dec. 19, 1905. Lyon. Crude-oil engine.
0,435. Jan. 23, 1906. Reynolds. Rotary explosive engine.
,860. Feb. 20, 1906. Low. Hydrocarbon motor.
3,796. Feb. 27, 1906. Holgate. Carburetor.
6,549. Mar. 27, 1906. Heckert. Gas engine.
22,172. May 29, 1906. Welcome. Internal-combustion engine.
823,742. June 19, 1906. Schmidt. Carburetor-control mechanism for motor vehicles.
830,744. Sept. 4, 1906. Frantz. Explosive engine.
*832,532. Oct. 2, 1906. Carlson & Shimpf. Carburetor.
*846,471. Mar. 12, 1907. Hobart. Feed governor for oil engines.
846,679. Mar. 12, 1907. Mason & Sinclair. Carburetor.
*849,538. Apr. 9, 1907. Gaeth. Carburetor.
852,272. Apr. 30, 1907. Hennig. Governing means for internal-combustion engines.
*855,582. June 4, 1907. Miller. Speed-controlling mechanism for explosive motors.
*862,574. July 2, 1907. Dalkranian. Carburetor.
867,605. Oct. 8, 1907. Rothe. Fuel-valve controller for hydrocarbon engines.
867,797. Oct. 6, 1907. Coleman. Engine starter.
868,281. Oct. 15, 1907. Low. Hydrocarbon motor.
*872,336. Dec. 3, 1907. Gibbs. Internal-combustion engine.
872,419. Dec. 3, 1907. Herbst. Charge-forming device for internal-combustion engines.
878,706. Feb. 11, 1908. Anderson. Carburetor.
883,240. Mar. 31, 1908. Sabathé. Internal-combustion engine.
891,322. June 23, 1908. Brennan. Carburetor for explosive engines.
892,726. July 7, 1908. Holgate. Carburetor.
*894,656. July 28, 1908. Johnston. Carburetor for internal-combustion engines.
895,222. Aug. 4, 1908. Winton & Anderson. Multiple-cylinder two-cycle explosion engine.
904,455. Nov. 17, 1908. De Roos. Vaporizing device for internal-combustion engine.
*904,508. Nov. 24, 1908. Carlin. Carburetor.
*904,855. Nov. 24, 1908. Enrico. Carburetor for internal-combustion engines.
906,783. Dec. 15, 1908. Du Brie. Apparatus for supplying fuel to gas engines.
*908,112. Dec. 29, 1908. Longnecker. Internal-combustion engine.
909,558. Jan. 12, 1909. Daellenbach. Internal-combustion engine.
913,121. Feb. 23, 1909. Frayer. Valve control.
921,934. May 18, 1909. Willard. Apparatus for producing gas from liquid hydrocarbons.
*922,145. May 18, 1909. Howarth. Carburetor.
*922,383. May 18, 1909. Brons. Hydrocarbon engine.
926,756. July 6, 1909. Low. Means for supplying air to hydrocarbon motors.
*928,939. July 27, 1909. Charter. Charge-forming device for gas engines.
*930,483. Aug. 10, 1909. Kershaw. Carburetor and like device for mixing gas or vapor and air.
*931,389. Aug. 17, 1909. Crook. Internal-combustion engine.
942,863. Dec. 7, 1909. McIntire. Apparatus for treating gas.

946,737. Jan. 18, 1910. Riotte. Pressure-regulated gas valve for engines.
948,744. Feb. 8, 1910. Shearer. Carburetor.
*959,066. May 24, 1910. Ottaway. Carburetor.
*961,152. June 14, 1910. Morse. Internal-combustion engine.
966,581. Aug. 9, 1910. McCarty. Device for alternating atomizer pressures.
973,240. Oct. 18, 1910. Torchebeuf & Lanneau. Carbureting lamp.
*973,602. Oct. 25, 1910. Williams. Carburetor.
*975,696. Nov. 15, 1910. Koontz. Carburetor.
*975,796. Nov. 15, 1910. Radcliffe. Internal-combustion engine.
*976,237. Nov. 22, 1910. Westmacott. Carburetor and vaporizer for internal-combustion engines.
976,885. Nov. 29, 1910. Kemp. Carbureting apparatus.
*977,813. Dec. 6, 1910. Marrder. Carburetor.
979,667. Dec. 27, 1916. Harpster. Vaporizer for internal-combustion engines.
979,787. Dec. 27, 1910. Noyes. Mixer for gases and liquids.
*979,908. Dec. 27, 1910. Willet. Carburetor.
980,946. Jan. 10, 1911. Heermans. Internal-combustion engine.
982,825. Jan. 31, 1911. Johnston. Mixing valve for hydrocarbon engines.
*983,307. Feb. 7, 1911. Perkins. Internal-combustion engine.
994,985. June 13, 1911. Deprez & Richir. Carburetor.
1,004,661. Oct. 3, 1911. Knapp. Purifying apparatus for acetylene gas.
*1,013,955. Jan. 9, 1912. Roberts. Carburetor.
*1,017,750. Feb. 20, 1912. Hanchett. Mixer for gaseous fuel.
1,023,402. Apr. 16, 1912. Whiting. Mixer for gaseous fuel.
1,025,814. May 7, 1912. Lemp. Fuel-supply system for explosive engines.
1,030,388. June 25, 1912. Cross. Motive-fluid mixer for internal-combustion engines.
1,036,812. Aug. 27, 1912. Edmonson. Separator and volatilizer.
1,038,300. Sept. 10, 1912. Crone. Combined vaporizer and priming pump.
1,054,205. Feb. 25, 1913. Illmer & Kunze. Internal-combustion engine.
1,056,760. Mar. 18, 1913. Watt. Gas mixer and heater for explosive engines.
*1,060,053. Apr. 29, 1913. Winkler. Carburetor.
1,064,106. June 10, 1913. Stewart. Auxiliary air supply means for internal-combustion engines.
1,066,391. July 1, 1913. Von Eicken. Producer of inert gases.
*1,069,502. Aug. 5, 1913. Wadsworth. Priming device for internal-combustion engines.
1,070,449. Aug. 19, 1913. Green et al. Air-admission regulator.
1,077,414. Nov. 4, 1913. Marsh. Cooling device for an engine.
*1,079,338. Nov. 25, 1913. Hazelton. Gaseous-fuel mixer.
1,082,007. Dec. 23, 1913. Brush. Gas-mixture producer.
1,083,111. Dec. 30, 1913. MacConaghy. Explosion motor.
*1,084,028. Jan. 13, 1914. Pierce. Carburetor.
1,096,585. May 12, 1914. Yost & Jahnke. Divided-spray injection engine.
1,099,445. June 9, 1914. Jaubert. Method of running internal-combustion engines.
*1,099,995. June 16, 1914. Page & Seldon. Carburetor.
1,101,271. June 23, 1914. Gentzen. Method of introducing fuel into internal-combustion engines.
1,106,935. Aug. 11, 1914. Freer. Vaporizer and carburetor.
*1,109,192. Sept. 1, 1914. Wright. Internal-combustion engine.
1,111,620. Sept. 22, 1914. Sheedy. Auxiliary air inlet and primer for internal-combustion engines.
*1,111,897. Sept. 29, 1914. Harrold. Mixing valve for explosive engines.
*1,116,192. Nov. 3, 1914. Winton. Vaporizing device.
1,117,354. Nov. 17, 1914. Erickson. Gasifying device for liquid fuel.
*1,117,641. Nov. 17, 1914. Cottle. Internal-combustion engine.
*1,117,642. Nov. 17, 1914. Cottle. Internal-combustion engine.
1,120,828. Dec. 15, 1914. Lowry. Fuel-supply system and starter for explosion engines.
1,124,706. Jan. 12, 1915. Conwell & Little. Heater for gaseous fuel.
*1,125,525. Jan. 19, 1915. Hathcock. Carburetor.
*1,131,157. Mar. 9, 1915. Percival & Patterson. Kerosene-gas generator.
*1,131,371. Mar. 9, 1915. Hatfield. Fuel-mixing device for internal-combustion engines.
1,132,420. Mar. 16, 1915. Andereau. Heater for gaseous fluids.

*1,136,368. Apr. 20, 1915. Riker. Regulating means for internal-combustion engines.
1,142,440. June 8, 1915. Kramer. Fuel pulverizer for internal-combustion engines.
*1,143,092. June 15, 1915. Unckles. Carburetor.
1,143,258. June 15, 1915. Dunham. Inspirator for internal-combustion engines.
*1,143,779. June 22, 1915. Pembroke. Carburetor.
*1,151,989. Aug. 31, 1915. Balassa. Carburetor.
1,158,179. Oct. 26, 1915. Clerk. Internal-combustion engine working with coke-oven and other gases.
*1,158,435. Nov. 2, 1915. Bourne. Carburetor.
*1,160,837. Nov. 16, 1915. Burnham. Carburetor.
1,160,897. Nov. 16, 1915. Holloway. Means for treating kerosene or the like for use in hydrocarbon engines.
1,161,095. Nov. 23, 1915. Westinghouse. Internal-combustion engine.
1,165,656. Dec. 28, 1915. Entz. Carburetor heater.
1,165,914. Dec. 28, 1915. Shaw. Fire-prevention means for internal-combustion engines.
*1,167,217. Jan. 4, 1916. Reichenbach. Carburetor.
*1,176,267. Mar. 21, 1916. Baverey. Carburetor.
Re. 4,476 (115,988). July 18, 1871. Sloper. Improvement in apparatus for carbureting air.
Re. 12,332. Mar. 28, 1905. Jacob. ———.

LIST NO. 3.

SELECTED PATENTS FROM SEARCHED SUBCLASSES ARRANGED ACCORDING TO CLASS AND SUBCLASS, WITH PATENTS WHICH APPEAR IN THE PREVIOUS LISTS OMITTED.

CLASS 123, INTERNAL-COMBUSTION ENGINES.

SUBCLASS 3, GENERATING PLANTS.

326,430. Sept. 15, 1885. James. Apparatus for manufacture, using and furnishing motive power by aid of air and hydrocarbon oils.
649,713. May 15, 1900. Woodward & Barckdall. Explosive engine.

SUBCLASS 4, INTERNAL COMBUSTION AND FLUID PRESSURE.

620,431. Feb. 28, 1899. Eisenhuth. Explosive engine for vehicles.
625,416. May 23, 1899. Revel. Carbureted air or other fluid pressure engine.
647,583. Apr. 17, 1900. Scott. Explosion engine.
651,780. June 12, 1900. Dawson. Interal-combustion motor.
729,652. June 2, 1903. Osborne. Motor.
790,344. May 23, 1905. Clark. Valve-gear mechanism.
832,592. Oct. 9, 1906. Bush. Motor.

SUBCLASS 7, HAMMERS.

*1,033,503. July 23, 1912. White & Duryea. Internal-combustion power hammer.
*1,033,505. July 23, 1912. White & Duryea. Power device.

SUBCLASS 8, ROTARY.

795,889. Aug. 1, 1905. Billinghurst. Internal-combustion turbine.
1,006,417. Oct. 17, 1911. Sullivan. Rotary compound explosive engine.

SUBCLASS 9, ROTARY IMPACT.

853,124. May 7, 1907. Schann. Turbine.
877,194. Jan. 21, 1908. Holzwarth. Gas turbine.
1,063,666. June 3, 1913. Duryea & White. Internal-combustion tool.
1,187,293. June 13, 1916. Faurot. Turbine.

SUBCLASS 10, ROTARY REACTION.

364,866. June 14, 1887. Seigneuret. Reaction wheel.

SUBCLASS 13, ROTARY ROTATING ABUTMENT.

868,678. Oct. 22, 1907. MacKasie. Rotary engine.
883,363. Mar. 31, 1908. Walker. Rotary explosive engine.
1,177,880. Mar. 28, 1916. Carpenter. Rotary explosive engine.

SUBCLASS 15, ROTARY, SWINGING ABUTMENT.

833,107. Oct. 9, 1906. Akerberg. Rotary engine.
930,601. Aug. 10, 1909. Kasparek. Rotary internal-combustion motor.

SUBCLASS 16, ROTARY, SLIDING PISTON.

260,513. July 14, 1882. Wigmore. Gas motor engine.
709,030. Sept. 16, 1902. McCahon. Combination air and vapor motor.

SUBCLASS 18, OSCILLATING PISTON.

1,080,272. Dec. 2, 1913. Fletcher. Engine.

SUBCLASS 20, STEAM CONVERTIBLE.

1,162,423. Nov. 30, 1915. Wentworth. Internal-combustion engine.

SUBCLASS 22, INTERNAL COMBUSTION AND AIR.

30,701. Nov. 20, 1860. Wilcox. Air engine.
Re. 1,942. Apr. 25, 1865. Wilcox. Improvement in hot-air engine.

SUBCLASS 25, WATER AND HYDROCARBON.

49,346. Aug. 8, 1865. Hugon. Improvement in gas engines.
591,346. Oct. 19, 1897. Mayhew. Gas engine.
597,860. Jan. 25, 1898. Rolfe. Explosion engine.
*819,239. May 1, 1906. Marks. Mixing and combining device for gas engines.
861,411. July 30, 1907. Weiss. Internal-combustion engine.
*917,283. Apr. 6, 1909. Frost. Internal-combustion engine.
1,008,825. Nov. 14, 1911. Holroyd. Apparatus for generating products of combustion.
*1,077,881. Nov. 4, 1913. Higgins. Process of mixing fuel for carburetors.
*1,148,166. July 17, 1915. Harrington. Explosion engine and method of operating the same.

SUBCLASS 28, OIL ENGINE, PUMP SUPPLY TO AIR INLET, FOUR-CYCLE.

349,369. Sept. 21, 1886. Spiel. Petroleum and gas engine.
349,464. Sept. 21, 1886. Spiel. Gas engine.
393,127. Nov. 20, 1888. Spiel. Petroleum engine.
426,337. Apr. 22, 1890. Sintz. Gas engine.
502,255. July 25, 1893. Hoyt. Gas engine.
527,635. Oct. 16, 1894. Voll. Gas engine.
*532,314. Jan. 8, 1895. Charter. Gas engine.
543,818. July 30, 1895. Weeks. Gas engine.
570,500. Nov. 3, 1896. Prouty. Gasoline and vapor engine.
574,610. Jan. 5, 1897. Joranson. Gas engine.
584,960. June 22, 1897. Quast. Explosive engine.
584,961. June 22, 1897. Quast. Gas engine.
597,326. Jan. 11, 1898. Quast. Gas engine.
607,878. July 26, 1898. Quast. Gas engine.
612,756. Oct. 18, 1898. Ostenberg. Gas engine.
624,975. May 16, 1899. Quast. Gas engine.
626,275. June 6, 1899. Froelich. Speed regulator for explosive engines.
665,714. Jan. 8, 1901. Zimmerman. Speed regulator for explosive engines.

672,615. Apr. 23, 1901. Doorenbos. Gas or gasoline engine.
694,948. Mar. 11, 1902. Davis. Explosive engine.
718,511. Jan. 13, 1903. Ostenberg. Explosion engine.
858,022. June 25, 1907. Podlesak. Fuel feeding device for internal-combustion motors.

SUBCLASS 34, OIL ENGINES, EXTERNAL VAPORIZING.

289,691. Dec. 4, 1883. Nash. Gas engine.
289,692. Dec. 4, 1883. Nash. Gas engine.
295,784. Mar. 25, 1884. Maxim. Gas engine.
331,079. Nov. 24, 1885. Nash. Explosive-vapor engine.
331,210. Nov. 24, 1885. Nash. Explosive-vapor engine.
334,041. Jan. 12, 1886. Nash. Method of operating explosive-vapor engines.
376,212. Jan. 10, 1888. Shanck. Gas engine.
378,328. Feb. 21, 1888. List & Kosakoff. Petroleum motor.
425,116. Apr. 8, 1890. Valentine & Grigg. Gas engine.
544,586. Aug. 13, 1895. Mead. Gas or oil engine.
583,399. May 25, 1897. Lewis. Gas or vapor engine.
*598,986. Feb. 15, 1898. Gere. Combustible-vapor engine.
615,766. Dec. 13, 1898. Vansickle. Gas engine.
648,914. May 8, 1900. Bertheau. Vaporizer for petroleum motors.
649,122. May 8, 1900. Allen. Rotary engine.
683,080. Sept. 24, 1901. Stewart. Gas engine.
701,140. May 27, 1902. Briggs. Hydrocarbon-oil engine.
736,807. Aug. 18, 1903. Wilkinson. Internal-combustion engine.
756,834. Apr. 12, 1904. Denison. Vaporizer for explosive engines.
770,872. Sept. 27, 1904. Söhnlein. Explosive engine.
805,774. Nov. 28, 1905. Blaisdell. Internal-combustion engine.
873,840. Dec. 17, 1907. Clift. Internal-combustion engine.
881,189. Mar. 10, 1908. Losch & Gerber. Explosive engine.
894,568. July 28, 1908. Avery. Gas engine.
899,186. Sept. 22, 1908. Rabsilber. Internal-combustion engine.
909,897. Jan. 19, 1909. Hertzberg. External electrical vaporizer for combustion engines.
909,900. Jan. 19, 1909. Hertzberg et al. Electrically heated starting vaporizer for internal-combustion engines.
961,581. June 14, 1910. Bowen. Explosive engine.
971,682. Oct. 4, 1910. Low. Economizer.
974,087. Oct. 25, 1910. Low. Charge-forming arrangement for use in internal-combustion engines and turbines.
975,008. Nov. 8, 1910. White. Method of operating gas engines and apparatus therefor.
977,847. Dec. 6, 1910. Wright. Internal-combustion engine.
1,003,795. Sept. 19, 1911. Rabsilber. Internal-combustion engine.
1,006,244. Oct. 17, 1911. Low & Hertzberg. Explosive engine.
1,026,871. May 21, 1912. Lake. Internal-combustion engine.
*1,060,053. Apr. 29, 1913. Winkler. Carburetor.
*1,128,958. Feb. 16, 1915. Duryea. Internal-combustion engine.
1,135,083. Apr. 13, 1915. Waite. Internal-combustion engine.
1,138,824. May 11, 1915. Wills. Internal-combustion engine.
1,152,003. Aug. 31, 1915. Butler. Gas producer for explosive engines.

SUBCLASS 35, OIL ENGINES, EXTERNAL VAPORIZING.

377,866. Feb. 14, 1888. Spiel. Petroleum engine.
399,569. Mar. 12, 1889. Schiltz. Petroleum engine.
412,228. Oct. 8, 1889. Altmann & Kuppermann. Petroleum motor.
425,909. Apr. 15, 1890. Roots. Petroleum engine.
428,764. May 27, 1890. Taverner. Engine or motor operated by explosive mixtures.
*437,507. Sept. 30, 1890. Otto. Petroleum or oil motor engine.
*440,485. Nov. 11, 1890. Lindley & Browett. Liquid hydrocarbon motor engine.
453,446. June 2, 1891. Lindner. Hydrocarbon engine.
482,201. Sept. 6, 1892. Schumm. Oil motor engine.

511,651. Dec. 26, 1893. Roots. Petroleum or liquid hydrocarbon engine.
518,151. Apr. 10, 1894. Knight. Vaporizer for hydrocarbon motors.
524,945. Aug. 21, 1894. Knight. Hydrocarbon motor.
544,879. Aug. 20, 1895. Best. Gas engine and generator.
549,677. Nov. 12, 1895. Mayer. Vapor engine.
552,686. Jan. 7, 1896. Carter. Petroleum-oil engine.
*565,033. Aug. 4, 1896. Robinson. Gas or oil engine.
*566,125. Aug. 18, 1896. Barker. Vaporizer for oil engines.
*578,034. Mar. 2, 1897. Bomborn. Vaporizer for petroleum engines.
582,271. May 11, 1897. Dawson. Oil or gas engine.
589,108. Aug. 31, 1897. Wordsworth. Motor worked by hydrocarbon or other gases.
600,107. Mar. 1, 1898. Wiseman & Holroyd. Hydrocarbon motor.
600,974. Mar. 22, 1898. Wiseman & Holroyd. Hydrocarbon motor.
633,319. Sept. 19, 1899. Inman. Carburetor.
668,773. Feb. 26, 1901. Hanson. Vaporizer for explosive engines.
*700,295. May 20, 1902. Bertheau. Four-stroke petroleum motor.
*725,191. Apr. 14, 1903. Allsop. Petroleum engine.
*728,873. May 26, 1903. Cundall. Oil engine.
733,417. July 14, 1903. Nicholson. Internal-cumbustion engine.
750,451. Jan. 26, 1904. Grant. Vaporizer for gas engine.
773,245. Oct. 25, 1904. Cappell. Coiling motors.
*860,630. July 23, 1907. Brady. Valve gear for internal-combustion engines.
*951,353. Mar. 8, 1910. Weller. Gas engine.
1,135,082. Apr. 13, 1915. Waite. Internal-combustion engine.
1,135,083. Apr. 13, 1915. Waite. Internal-combustion engine.
1,157,287. Bellem & Bregeras. Internal-combustion engine.
Re. 11,633. Oct. 12, 1897. Gas engine and generator.

SUBCLASS 52, MULTIPLE CYLINDER.

*1,128,717. Feb. 16, 1915. Ottaway. Carburetor.
1,159,985. Nov. 9, 1915. Orlopp. Fuel connection for internal-combustion engines.

SUBCLASS 73, TWO-CYCLE, REAR-COMPRESSION CRANK CASE.

*1,096,819. May 19, 1914. Ahlberg. Internal-combustion engine.
*1,102,025. June 30, 1914. Ellis. Fuel injector for explosion engines.
*1,139,364. May 11, 1915. Obergfell. Internal-combustion engine.

SUBCLASS 76, FOUR-CYCLE SCAVENGING.

1,146,864. July 20, 1915. Gibson. Internal-combustion engine.

SUBCLASS 98, SPEED REGULATORS, MANUALLY CONTROLLED.

*775,103. Nov. 15, 1904. Duryea. Internal-combustion engine.
*872,138. Nov. 26, 1907. Mayer. Valve gear.
962,248. June 21, 1910. Rockwell. Mechanism for feeding fuel.
*998,355. July 18, 1911. Lee. Carburetor for internal-combustion engines.
1,020,379. Mar. 12, 1912. Weiwoda. Throttle valve for carburetors.
*1,029,685. June 18, 1912. Huff. Controlling mechanism for motor vehicles.

SUBCLASS 99, SPEED REGULATORS, COMBINED TYPES.

368,444. Aug. 16, 1887. Baldwin. Gas engine.
1,138,831. May 11, 1915. Baker et al. Internal-combustion engine.
*1,153,364. Sept. 14, 1915. Warner. Internal-combustion engine.
1,186,037. June 6, 1916. Purdy. Control system for internal-combustion engines.

SUBCLASS 100, SPEED REGULATORS, CHARGE VOLUME PROPORTION VARYING.

408,683. Aug. 13, 1889. Baldwin. Gas engine.
*862,574. Aug. 6, 1907. Messinger. Carburetor.
*985,703. Feb. 28, 1911. Podlesak. Internal-combustion engine.

*1,014,328. Jan. 9, 1912. Podlesak. Mixture-producing and speed-governing device for gas engines.
*1,064,514. June 10, 1913. Mees. Method of regulating and controlling the valve motion in explosive motors.

SUBCLASS 101, SPEED REGULATORS, CHARGE VARYING AND OMITTING.

*754,001. Mar. 8, 1904. Mutel. Regulating device for engines.

SUBCLASS 102, SPEED REGULATORS, ELECTRICAL.

*727,565. May 12, 1903. Apple. Electric governor for gas engines.
1,089,478. Mar. 10, 1914. Kasley. Explosion motor.

SUBCLASS 103, SPEED REGULATORS, PNEUMATIC.

*626,120. May 30, 1899. Winton. Explosive engine.
663,183. Dec. 4, 1900. Millot. Speed governor for explosive engines.
762,965. June 21, 1904. Washburne. Feed mechanism for explosive engines.
782,244. Feb. 14, 1905. Haydon. Governor for explosion engines.
1,142,219. June 8, 1915. Ziegler. Governing and throttling device for internal-combustion engines.

SUBCLASS 104, SPEED REGULATORS, SUPPLY PUMP, REGULATING.

906,022. Dec. 8, 1908. Hesselmann. Fuel pump ofr reversible internal-combustion engine.
1,017,591. Feb. 13, 1912. Rigby. Method of governing internal-combustion engines.
1,067,424. July 15, 1913. Hamke. Fuel pump for internal-combustion engines.
1,166,230. Dec. 28, 1915. Lemp. Fuel pump.

SUBCLASS 106, CHARGE PROPORTION VARYING.

1,075,635. Oct. 14, 1913. Elkin. Carburetor.
1,083,433. Jan. 6, 1914. Crist. Explosion motor.
1,089,462. Mar. 10, 1914. Crist. Explosion motor.
1,107,103. Aug. 11, 1914. Peaslee. Carburetor.
*1,144,549. June 29, 1915. Kane. Carbureting internal-combustion engines.

SUBCLASS 108, THROTTLING.

*882,170. Mar. 17, 1908. Schmidt. Carburetor.
*889,032. May 26, 1908. McClintock. Combined carburetor and governor for internal-combustion engines.
*1,105,142. July 28, 1914. Jager. Internal-combustion engine.
1,130,103. Mar. 2, 1915. Plumm. Throttle valve for carburetors.
*1,149,597. Aug. 10, 1915. Riker. Regulating means for internal-combustion engines.

SUBCLASS 112, SUPPLY-VALVE REGULATING.

*599,376. Feb. 22, 1898. White. Gas-engine attachment.

SUBCLASS 117, AUTOMATICALLY CONTROLLED IGNITING DEVICES.

1,163,692. Dec. 14, 1915. Royce. Controlling device for the electrical ignition systems of internal-combustion engines.

SUBCLASS 122, CHARGE-FORMING DEVICES, HEATING.

276,075. Apr. 17, 1883. Quick. Tramway locomotive.
400,850. Apr. 2, 1889. Humes. Hydrocarbureted air engine.
407,961. July 30, 1889. McNett. Combined gas engine and carburetor.
*573,762. Dec. 22, 1896. Charter. Gas engine.
*657,738. Sept. 11, 1900. Jessen. Carburetor for explosive engine.
*673,901. May 14, 1901. Eckhard. Mixer and vaporizer for gas engines.

*676,285. June 11, 1901. Van Duzen. Spraying and vaporizing device for crude-oil explosive engines.
*759,001. May 3, 1904. Mohler. Carburetor for hydrocarbon engines.
766,530. Aug. 2, 1904. Salisbury. Apparatus for generation of gas.
776,982. Dec. 6, 1904. Anderson. Carbureting apparatus for explosive engines.
854,096. May 21, 1907. Levering. Gas engine.
862,377. Aug. 6, 1907. Bacon. Explosive engine.
900,083. Oct. 6, 1908. ———. Gas engine.
916,999. Apr. 6, 1909. Chambers. Air heater for gasoline engines.
920,167. May 4, 1909. McIntyre. Internal-combustion engine.
946,239. Jan. 11, 1910. Low et al. Internal-combustion engine.
967,117. Aug. 9, 1910. Durand. Means for cooling the cylinders of internal-combustion engines.
968,002. Aug. 23, 1910. Utz. Induction conduit for explosion engines.
971,034. Sept. 27, 1910. Fuller. Air intake for carburetors.
972,547. Oct. 11, 1910. Law. Gas engine.
986,357. Mar. 7, 1911. Bullert. Hot-air intake.
990,741. Apr. 25, 1911. Jacobs. Fuel feeding means for explosive engines.
*994,658. June 6, 1911. Reichenbach. Carbureting system.
998,124. July 18, 1911. Scripps. Intake manifold.
1,032,937. July 16, 1912. Pierce. Carburetor heater.
1,035,614. Aug. 13, 1912. Low et al. Vaporizing device for explosive engines.
1,048,576. Dec. 31, 1912. Page. Heating device for carburetors.
1,050,625. Jan. 14, 1913. Dortch. Internal-combustion engine.
*1,067,906. July 22, 1913. Esnault et al. Device for heating the carburetors of combustion engines and more particularly for flying-machine engines.
1,078,919. Nov. 18, 1913. Hall. Internal-combustion engine.
1,083,673. Jan. 6, 1914. Ellis. Internal-combustion engine.
1,093,756. Apr. 21, 1914. Beasley. Device for heating charges for explosive engines.
1,099,271. June 9, 1914. Sykora. Internal-combustion engine.
1,099,842. June 9, 1914. Cobb. Manifold construction for explosive engines.
1,099,862. June 9, 1914. Schroder. Method of operating internal-combustion engines and preheating device therefor.
1,101,365. June 23, 1914. Weaver. Fuel heater for internal-combustion engines.
*1,101,913. June 30, 1914. Fay. Internal-combustion engine.
*1,103,451. July 14, 1914. Thorney. Combustion engine.
*1,105,017. July 28, 1914. Bassford. Explosive engine.
1,106,452. Aug. 11, 1914. Ittner. Gasoline vaporizer.
*1,106,881. Aug. 11, 1914. Marnyama. Internal-combustion engine.
1,109,628. Sept. 1, 1914. Hallett. Rotary valve for explosive engines.
1,110,724. Sept. 15, 1914. Stewart. Carbureting means for use with heavy fuels.
1,112,589. Oct. 6, 1914. Ashmusen. Internal-combustion engine.
1,124,157. Jan. 5, 1915. Low. Internal-combustion engine using liquid fuel.
1,124,916. Jan. 12, 1915. Knudson. Manifold for internal-combustion engines.
1,125,446. Jan. 19, 1915. Beasley. Device for heating charges for explosive engines.
1,131,016. Mar. 9, 1915. Thornton et al. Air-heating device for explosive engines.
1,133,712. Mar. 30, 1915. Doyle. Cooling system.
*1,133,845. Mar. 30, 1915. Farnsworth. Explosive engine.
1,134,667. Apr. 6, 1915. Brooke. Internal-combustion engine.
1,135,074. Apr. 13, 1915. Taylor et al. Explosion engine.
1,135,113. Apr. 13, 1915. Hitchcock. Vapor heater for internal-combustion engines.
*1,137,057. Apr. 27, 1915. Halliday. Heavy-oil carbureting system for internal-combustion engines.
1,142,090. June 8, 1915. Griesbach. Vaporizer for internal-combustion engines.
1,149,710. Aug. 10, 1915. Beck. Heavy-oil carburetor for explosive engines.
1,151,503. Aug. 24, 1915. Wilesmith. Apparatus for heating the combustible charges of internal-combustion engines.
1,152,744. Sept. 7, 1915. McNutt. Revaporizer for internal-combustion engines.
1,159,446. Nov. 9, 1915. Watts. Carburetor.

1,160,192. Nov. 16, 1915. Nelson. Carburetor warmer.
1,168,111. Jan. 11, 1915. Pope. Fuel-heating apparatus for internal-combustion engines.
1,170,337. Feb. 1, 1916. Robinson et al. Air heater for carburetors.
*1,171,145. Feb. 8, 1915. Lachs. Carburetor.
1,178,276. Apr. 4, 1916. Straubel. Fuel-heating device for internal-combustion engines.
*1,178,972. Apr. 11, 1916. Tracy. Charge-forming device for internal-combustion engines.
1,180,176. Apr. 18, 1916. Moreton. Carbureting apparatus.
1,190,129. July 4, 1916. DuBois. Carburetor heater.
*1,190,592. July 11, 1916. Roraback. Manifold for gas engines.

SUBCLASS 123, CHARGE-FORMING DEVICES, GOVERNOR-CONTROLLED.

371,849. Oct. 18, 1887. Lister et al. Petroleum motor.
397,517. Feb. 12, 1889. Priestman. Method of working hydrocarbureted air engines.
509,462. Nov. 28, 1893. Caps. Carburetor for gas engines.
*552,263. Dec. 31, 1895. Roth. Generator for gas engines.
580,387. Apr. 13, 1897. Ellis. Explosive engine.
*583,508. June 1, 1897. Raymond. Gas engine.
*596,809. Jan. 4, 1898. Guyer. Gas engine.
*614,114. Nov. 15, 1898. Lefebre. Oil or similar motor.
638,440. Dec. 5, 1899. Brillie. Combined distributor and regulator for explosive engines.
*659,095. Oct. 2, 1900. Olsen. Gasoline engine.
*671,714. Apr. 9, 1901. Wolfe. Governing device for gasoline engines.
686,554. Nov. 12, 1901. Stearns. Speed regulator for explosive engines.
*709,126. Sept. 16, 1902. Vanduzen. Vaporizing device for explosive engines.
722,671. Mar. 17, 1903. Burger. Gas engine
*722,672. Mar. 17, 1903. Burger. Valve for gas engines.
*729,377. May 26, 1903. Meister et al. Combined governor and gas and air mixer for explosive engines.
731,999. June 23, 1903. Hagan. Carburetor and governor for hydrocarbon engines.
*734,421. July 21, 1903. Krebs. Fuel governor for oil engines.
*735,483. Aug. 4, 1903. Hydrocarbon mixer and regulator for engines.
*779,490. Jan. 10, 1905. McKaig. Mixing apparatus for explosion or gasoline engines.
*782,471. Feb. 14, 1905. Sterne et al. Internal-combustion engine.
*788,748. May 2, 1905. Bauer. Gas and oil engine.
*794,192. July 11, 1905. Seal. Internal-combustion engine.
806,512. Dec. 5, 1905. Abraham. Carburetor for hydrocarbon engines.
863,916. Aug. 20, 1907. Gronvelle et al. Speed regulator for internal-combustion engines.
*876,519. Jan. 14, 1908. Brothers. Charge forming device for internal combustion engines.
*885,598. Apr. 21, 1908. Frost. Internal-combustion engine.
904,960. Nov. 24, 1908. Hukle. Carburetor and mixer.
*955,218. Apr. 19, 1910. Smith. Carburetor.
970,429. Sept. 13, 1910. Davis. Carburetor for internal-combustion engines.
1,075,635. Oct. 14, 1913. Elkin. Carburetor.
*1,076,268. Oct. 21, 1913. Carpenter. Carburetor regulating mechanism.
*1,123,508. Jan. 5, 1915. Farrell. Carburetor.
1,133,679. Mar. 30, 1915. Taylor. Governor for internal-combustion engine.
*1,151,156. Aug. 24, 1915. Bingaman. Carburetor.
*1,154,530. Sept. 21, 1915. Merriam et al. Carburetor.
*1,155,094. Sept. 28, 1915. Podlesak. Mixture-reducing device and speed governor.
1,170,199. Feb. 1, 1916. Ver Planck. Governing mechanism for internal-combustion engines.

SUBCLASS 124, CHARGE-FORMING DEVICES, AUTOMATIC DILUTION.

642,871. Feb. 6, 1900. New. Heavy oil engine.
*751,434. Feb. 2, 1904. Napier et al. Carburetor for petrol motors.
823,185. June 12, 1906. Miller. Air valve for gas engines.

*831,832. Sept. 25, 1906. Coffin. Carburetor for hydrocarbon engines.
*838,085. Dec. 11, 1906. Cook. Carburetor for explosive engines.
*844,894. Feb. 19, 1907. Renault. Carburetor.
871,361. Nov. 19, 1907. Reineking. Air intake regulator for carburetors.
878,077. Feb. 4, 1908. Longuemare.
891,936. June 30, 1908. Jordanet et al. Carburetor.
894,286. July 28, 1908. Reineking. Air intake and regulator for carburetors.
906,039. Dec. 8, 1908. Le Plain. Automatic double air inlet for carburetors.
939,549. Nov. 9, 1909. Reineking. Reed air-intake regulator for carburetors.
943,996. Dec. 21, 1909. Reineking. Reed air-intake regulator for carburetors.
*997,232. July 4, 1911. Bowers. Carburetor.
1,050,200. Jan. 14, 1913. Aubery. Auxiliary air inlet device for internal-combustion engines.
1,086,112. Feb. 3, 1914. Winkler. Mixture regulator.
1,088,302. Feb. 24, 1914. Scudder. Automatic air valve for gas manifolds.
1,117,676. Nov. 17, 1914. Johnson. Automatic carburetor air supply regulator.
1,117,993. Nov. 24, 1914. Frazier. Automatic valve.
1,142,194. June 8, 1915. Morgan. Auxiliary valve for internal-combustion engines.
1,142,779. June 8, 1915. Umbarger. Gas-saving appliance.
*1,143,230. June 15, 1915. Root. Air-controlled device for gas engines.
1,168,309. Jan. 18, 1916. Keiffer. Auxiliary valve for internal-combustion engines.
1,171,457. Feb. 15, 1916. Oldham. Air controller for explosive engines.
*1,189,786. July 4, 1916. Byrnes. Thermostatic-control device for explosive engines.

SUBCLASS 125, CHARGE-FORMING DEVICES, OIL INTERRUPTING.

370,242. Sept. 20, 1887. Charter. Gas engine.

SUBCLASS 126, CHARGE-FORMING DEVICES, MOVABLE CARRIER.

550,410. Nov. 26, 1895. Hardina. Gas generator.
712,42. Nov. 4, 1902. Jeffery. Carburetor for explosive engines.
1,184,779. May 30, 1916. Shaw. Aerating fuel pump for explosive motors.

SUBCLASS 127, CHARGE-FORMING DEVICES, MULTIPLE OIL SUPPLY.

*1,105,016. July 28, 1914. Bassford. Explosive engine.
*1,110,438. Sept. 15, 1914. Gore. Internal-combustion engine.
1,115,967. Nov. 3, 1914. Papenbrok. Attachment for explosive engines.
1,121,135. Dec. 15, 1914. Schmid. Internal-combustion engine.
1,180,169. Apr. 18, 1916. Marhenke. Fuel-injecting device for internal-combustion engines.

SUBCLASS 128, CHARGE-FORMING DEVICES, CONSTANT OIL SUPPLY.

665,665. Jan. 8, 1901. Solomon. Gas engine.
670,945. Apr. 2, 1901. Ash. Vaporizing device for gas engines.
731,001. June 16, 1903. Williams. Explosive engine.
1,189,338. July 4, 1916. Askew. Internal-combustion engine.

SUBCLASS 129, CHARGE-FORMING DEVICES, VALVE-CONTROLLED OIL.

*418,029. Dec. 24, 1889. Korting. Automatic valve and ignitor for gas engines.
*598,832. Feb. 8, 1898. Winton. Explosive engine.
*748,990. Jan. 5, 1904. Segner. Feed regulator for gasoline engines.
*795,273. July 25, 1905. Essner. Carburetor.
*868,392. Oct. 15, 1907. Allsop. Petroleum engine.
*877,753. Jan. 28, 1908. Ash. Gas engine.
*887,422. May 12, 1908. Power. Mixing valve for internal-combustion engines.

SUBCLASS 130, CHARGE-FORMING DEVICES, VALVE-CONTROLLED OIL, POSITIVELY-OPERATED.

*517,344. Mar. 27, 1894. Lambert. Carburetor.
731,547. June 23, 1903. Corne et al. Carburetor for explosion motors.
827,303. July 31, 1906. Goodspeed. Valve gear for internal-combustion engines.
1,159,178. Nov. 2, 1915. Cook. Injector.

SUBCLASS 133, CHARGE-FORMING DEVICES, OIL-EVAPORATING.

39,448. Aug. 4, 1863. Kratze. Improvements in gas engines.
331,078. Nov. 24, 1885. Nash. Explosive-vapor engine.
335,462. Feb. 2, 1886. Lenoir. Gas engine.
480,535. Aug. 9, 1892. Weatherhogg. Petroleum or similar engine.
577,189. Feb. 16, 1897. Lewis. Vapor engine.
606,504. June 28, 1898. Bonton. Explosive engine.
*635,298. Oct. 24, 1899. Canda. Carburetor.
784,676. Mar. 14, 1905. Hiltscher. Carburetor for gas engines.
785,808. Mar. 28, 1905. Keating. Carburetor for hydrocarbon engines.
*844,900. Feb. 19, 1907. Smith. Carburetor.
*858,046. June 25, 1907. Westerndorp. Vaporizer for explosive engines.
868,246. Oct. 15, 1907. Bates. Generating oil gas for explosive engines.
879,659. Feb. 18, 1908. Low. Hydrocarbon motor.
934,599. Sept. 21, 1909. Flint. Apparatus for vaporizing hydrocarbon oils.
1,110,807. Sept. 15, 1914. Lucke. Vaporizer for internal-combustion engines.
1,111,140. Sept. 22, 1914. Deering. Gas-generating system.
1,156,780. Oct. 12, 1915. Honnold. Combined fuel and cooling system for vehicle engines.

SUBCLASS 134, CHARGE-FORMING DEVICES, OIL-EVAPORATING, SUBMERGED AIR SUPPLY.

499,597. June 13, 1893. Salomon. Carburetor.
642,562. Jan. 30, 1900. Probert. Vaporizer for gas engines.

SUBCLASS 135, CHARGE-FORMING DEVICES, EXTENDED OIL FILM.

406,540. July 9, 1889. Schlitz. Hydrocarbon engine.
651,017. June 5, 1900. Marne. Carburetor.
685,504. Oct. 29, 1901. Bole et al. Carburetor.
*947,633. Jan. 25, 1910. Brady. Internal-combustion engine.
1,185,224. May 30, 1916. Manley. Internal-combustion engine.

SUBCLASS 136, CHARGE-FORMING DEVICES, OIL-FEEDING.

200,970. Mar. 5, 1878. Brady. Improvement in gas engines.
496,751. May 2, 1893. Schumm. Apparatus for supplying oil or other liquids under pressure.
509,830. Nov. 28, 1893. Seck. Hydrocarbon motor.
645,458. Mar. 13, 1900. ———. Oil-distributing means for oil engines.
652,470. June 26, 1900. Cascaden et al. Explosive engines.
686,287. Nov. 12, 1901. Grenter. Feed mechanism for gasoline or like engines.
*709,428. Sept. 16, 1902. Warring. Hydrocarbon feeder for explosive engines.
752,181. Feb. 16, 1904. Ronan. Raw liquid fuel measurer for explosive engines.
817,671. Apr. 10, 1906. Rosseau et al. Oil engine.
*849,048. Apr. 2, 1907. Cable. Fuel feed for hydrocarbon engines.
890,522. June 9, 1908. MacKaskie. Charge-supplying means for internal-combustion engines.
933,325. Sept. 7, 1909. McCartey. Fuel feeder for internal-combustion engine.
973,880. Oct. 25, 1910. Rammen. Auxiliary liquid hydrocarbon tank for internal-combustion engine.
997,136. July 4, 1911. Johnston. Device for supplying oil to internal-combustion engine.
1,002,626. Sept. 5, 1911. Baltezor. Internal-combustion engine.
1,011,931. Dec. 19, 1911. Farquharson. Force-feed carburetor.
1,036,424. Aug. 20, 1912. Bellem et al. Pump feeding mechanism for internal-combustion engines.
1,049,815. Jan. 7, 1913. Day et al. Starting mechanism for internal-combustion engines.
1,095,763. May 5, 1914. Winton. Fuel-supply system for automobiles.
*1,106,115. Aug. 4, 1914. Schneider. Charge-forming device for internal-combustion engines.
1,112,975. Oct. 6, 1914. Bush. Oil-distributing mechanism.
1,154,994. Sept. 28, 1915. Lasche. Fuel-supply system for engines.
1,189,096. June 27, 1916. Grunwald. Pumping apparatus.

SUBCLASS 137, CHARGE-FORMING DEVICES, OIL FEEDING, RECIPROCATING.

650,266. May 22, 1900. McDuff. Feed for explosion engines.
664,981. Jan. 1, 1901. Thornton et al. Oil-feeding device for explosion engines.
722,431. Mar. 10, 1903. Packard. Hydrocarbon motor.
880,502. Mar. 3, 1908. Boyler. Carburetor for explosion engines.

SUBCLASS 138, CHARGE-FORMING DEVICES, OIL FEEDING, ROTARY.

580,444. Apr. 13, 1897. Baker. Gas engine.
626,840. June 13, 1899. MacCallum. Apparatus for injecting fuel into combustion chambers of internal-combustion engines.
770,731. Sept. 27, 1904. Anderson. Feed valve for explosive engines.
1,177,216. Mar. 28, 1916. Summers. Carburetor.
1,180,334. Apr. 25, 1916. Summers. Carburetor.
1,188,572. June 27, 1916. Summers. Carburetor.

SUBCLASS 139, CHARGE-FORMING DEVICES, PUMPS.

774,034. Nov. 1, 1904. Brillie. Fuel-feeding mechanism for internal-combustion motors.
1,011,931. Dec. 19, 1911. Farquharson. Force-feed carburetor.

SUBCLASS 140, CHARGE-FORMING DEVICES, GOVERNOR CONTROL.

970,429. Sept. 13, 1910. Davis. Carburetor for internal-combustion engines.

SUBCLASS 141, CHARGE-FORMING DEVICES, MIXING DEVICES.

650,736. May 29, 1900. Sutton. Explosive engine.
* 755,093. Mar. 22, 1904. Wright. Vaporizer for hydrocarbon engines.
* 868,707. Oct. 22, 1907. Schneider. Carburetor.
948,402. Feb. 8, 1910. Preston. Vaporizing and mixing device.
* 970,251. Sept. 13, 1910. Martha. Internal-combustion engine.
1,012,380. Dec. 19, 1911. Loose. Mixer for internal-combustion engines.
1,031,753. July 9, 1912. Westaway. Mixer for internal-combustion engines or the like.
1,051,369. Jan. 21, 1913. Heath. Charge-mixing device for gas engines.
1,103,931. July 21, 1914. Bennett. Intake manifold.

SUBCLASS 142, CHARGE-FORMING DEVICES, SAFETY DEVICES.

434,695. Aug. 19, 1890. Barrett et al. Gas or vapor engine attachment.
928,710. July 20, 1909. Svagell. Carburetor.

SUBCLASS 180, COMBUSTIBLE MIXTURE SUPPLY STARTING DEVICES.

882,597. Mar. 24, 1908. Walker. Starting device for internal-combustion engines.
892,544. July 7, 1908. Odenbrett. Engine starter.
920,515. May 4, 1909. Nagora. Starting device for explosive engines.
921,995. May 18, 1909. Jackson. Auxiliary starting device for automobiles.
960,690. June 7, 1910. Pagelsen. Starting device for explosive engines.
969,815. Sept. 13, 1910. Walker. Starting device for internal-combustion engines.
983,168. Jan. 31, 1911. Sackrider. Starter for internal-combustion engines.
985,011. Feb. 21, 1911. Daniels et al. Gas-engine starter.
990,135. Apr. 18, 1911. Hunt. Engine starter.
1,000,595. Aug. 15, 1911. Gibbon. Starting device for internal-combustion engines.
*1,014,988. Jan. 16, 1912. Hinkley. Carburetor.
*1,039,229. Sept. 24, 1912. Walker. Carburetor.
1,051,122. Jan. 21, 1913. Krayer. Means for supplying explosive mixture to explosive engines.
1,161,536. May 13, 1913. Fuhrer. Gasoline engine starter.
1,080,773. Dec. 9, 1913. Myers. Engine starter.
1,081,534. Dec. 16, 1913. Priming attachment for explosive engines.
1,088,792. Mar. 3, 1914. Perkins. Explosive engine priming mechanism.
1,100,091. June 16, 1914. Pennington. Engine starter.

1,102,091. June 30, 1914. Shockley et al. Starting mechanism for internal-combustion engines.
1,102,475. July 7, 1914. Cochran. Means for creating and supplying explosive mixture to explosive engines.
1,117,141. Nov. 10, 1914. Smith. Explosive mixture heater and diluter.
1,157,868. Oct. 26, 1915. Higgins. Carburetor.
1,164,357. Dec. 14, 1915. Kaufmann. Primer.

CLASS 261, GAS AND LIQUID CONTACT APPARATUS.

SUBCLASS 10, WITH HEATING OR COOLING, INTERCHANGING.

353,653. May 14, 1907. Stewart. Gasifier.

SUBCLASS 12, WITH HEATING OR COOLING, HEATING.

360,954. Oct. 30, 1900. Hayes. Fuel vaporizer and mixer for explosive engines and other uses.
372,500. Apr. 23, 1901. Van Duzen. Vaporizing device for crude oil explosive engines.
*733,695. July 14, 1903. Charron & Gerardot. Pulverizing carburetor for petroleum motors.
*817,051. Apr. 3, 1906. Dorman. Carburetor for explosive motors and engines.
909,897. Jan. 19, 1909. Hertzberg. External electrical vaporizer for combustion engines.

SUBCLASS 13, WITH HEATING OR COOLING, HEATING, GAS.

*668,953. Feb. 26, 1901. Dawson. Vaporizing device for explosive engines.
*Re. 12,322. Feb. 28, 1905. Dawson. Vaporizing device for explosive engines.

SUBCLASS 15, WITH HEATING OR COOLING, HEATING, LIQUID.

*804,589. Nov. 14, 1905. Enrico. Carburetor for explosion motors.

SUBCLASS 26, FLUID DISTRIBUTION, PUMPING, AUTOMATIC CONTROL.

270,927. Jan. 23, 1883. Brayton. Regulating the supply of oil to vapor engines.

SUBCLASS 38, FLUID DISTRIBUTION, VALVED.

993,516. May 30, 1911. Gentle. Carburetor.
996,018. June 20, 1911. Heine. Carburetor and relief valve for explosive engines.

SUBCLASS 41, FLUID DISTRIBUTION, VALVED, MULTIPLE JET, PROGRESSIVE.

818,853. Apr. 24, 1906. Renault. Carburetor.

SUBCLASS 44, FLUID DISTRIBUTION, VALVED, MULTIPLE VALVES, CONNECTED.

751,913. Feb. 9, 1904. Haynes and Apperson. Carbureting device for explosive engines.

SUBCLASS 50, FLUID DISTRIBUTION, VALVED, MULTIPLE VALVES, CONNECTED, LIQUID INLET, WITH GAS INLET.

687,840. Dec. 3, 1901. Krasten. Fuel-mixing and charge-controlling apparatus for hydrocarbon explosive engines.
970,251. Sept. 13, 1910. Martha. Internal-combustion engine.
1,114,222. Oct. 20, 1914. Bingham. Carburetor.

SUBCLASS 51, FLUID DISTRIBUTION, VALVED, MULTIPLE VALVES, CONNECTED, LIQUID INLET, WITH GAS OUTLET.

627,372. June 20, 1899. Winton. Fuel feeder or regulator for explosive engines.
635,298. Oct. 24, 1899. Canda. Carburetor.
686,287. Nov. 12, 1901. Greuter. Feed mechanism for gasoline or like engines.
868,707. Oct. 22, 1907. Schneider. Carburetor.
906,671. Dec. 15, 1908. Abernethy. Carburetor for explosive engines.

SUBCLASS 54, FLUID DISTRIBUTION, VALVED, MULTIPLE VALVES, GAS BY-PASS.

891,936. June 30, 1908. Jordanet et al. Carburetor.

SUBCLASS 59, FLUID DISTRIBUTION, VALVED, MULTIPLE VALVES, LIQUID INLET, WITH GAS INLET.

675,424. June 4, 1901. Sturtevant. Carburetor for explosive engines.

SUBCLASS 62, FLUID DISTRIBUTION, VALVED, CONTACT SPACE.

*811,397. Jan. 30, 1906. Hibbard. Vaporizer.

SUBCLASS 65, FLUID DISTRIBUTION, VALVED, GAS OUTLET.

731,001. June 16, 1903. Williams. Explosive engine.

SUBCLASS 67, FLUID DISTRIBUTION, VALVED, LIQUID INLET, PLURAL

*692,444. Feb. 4, 1902. Harris. Carburetor for explosive engines.

SUBCLASS 68, FLUID DISTRIBUTION, VALVED, LIQUID INLET, PLURAL, FLOAT AND MANUAL.

*844,900. Feb. 19, 1907. Smith. Carburetor.

SUBCLASS 81, CONTACT DEVICES, RECIPROCATING.

862,856. Aug. 6, 1907. Tygard. Vibrative liquid atomizer and mixer.

SUBCLASS 84, CONTACT DEVICES, ROTATING, IMPELLER.

610,040. Aug. 30, 1898. Ford. Carburetor.
1,114,764. Oct. 27, 1914. Hopkins. Fluid-fuel feeder.

SUBCLASS 104, CONTACT DEVICES, POROUS SHEETS, SURFACE CONTACT, CAPILLARY FEED.

39,448. Aug. 4, 1863. Kratze. Improvement in gas engines.

SUBCLASS 105, CONTACT DEVICES, POROUS SHEET, GAS FLOW, CONTROL.

986,605. Mar. 14, 1911. Svagel & Padfield. Carburetor for gas and gasoline engines.

CLASS 60, MISCELLANEOUS HEAT-ENGINE PLANTS.

SUBCLASS 4, ROTARY ENGINE.

1,185,982. June 6, 1916. Casro. Fluid mixer and power generator for rotary engine.

SUBCLASS 36, COMBUSTION PRODUCTS INJECTED.

1,024,079. Apr. 23, 1912. Jennings. Internal-combustion generator.

LIST NO. 4.

SELECTED CROSS-REFERENCE PATENTS FROM THE SEARCHED SUBCLASSES, WITH PATENTS WHICH APPEAR IN EITHER OF THE THREE PREVIOUS LISTS OMITTED.

3,597. May 25, 1844. Perry. Gas engine.
4,800. Oct. 7, 1846. Perry. Gas engine.
168,623. Oct. 11, 1875. Daimler. Air and gas engine.
195,585. Sept. 25, 1877. Dreckmann. Gas engines.
258,884. June 6, 1882. Burritt. Gas motor engine.
260,513. July 4, 1882. Wigmore. Gas motor engine.
301,009. June 24, 1884. Rachholz. Gas engine.
322,062. July 14, 1885. Nash. Combined fuel converter and gas engine.

331,080. Nov. 24, 1885. Nash. Method of operating gas engine.
333,838. Jan. 5, 1886. Delamare et al. Gas engine.
339,225. Apr. 6, 1886. Sintz. Gas engine.
340,453. Apr. 20, 1886. Nash. Gas engine.
347,469. Aug. 17, 1886. Clark. Gas engine.
347,656. Aug. 17, 1886. Smith. Gas engine.
383,775. May 29, 1888. Sintz. Gas engine.
402,549. Apr. 30, 1889. Wilcox. Gas or air engine.
414,173. Oct. 29, 1889. Stevens. Combined gas and compressed air engine.
415,446. Nov. 19, 1889. Charter. Hydrocarbon or gas engine.
*417,924. Dec. 24, 1889. Korting. Method of automatic ignition in gas engines.
421,478. Feb. 18, 1890. Baker. Gas engine.
424,000. Mar. 25, 1890. Hibbard. Rotary gas engine.
*433,806. Aug. 5, 1890. Otto. Motor engine worked by oil vapor.
*433,807. Aug. 5, 1890. Otto. Motor engine worked by oil vapor.
436,936. Sept. 23, 1890. Eisenhuth. Explosive engine.
439,200. Oct. 28, 1890. Shanck. Gas engine.
439,702. Nov. 4, 1890. Stuart. Petroleum engine or motor.
*448,386. Mar. 17, 1891. Vanduzen. Gas or gasoline engine.
451,621. May 5, 1891. Lewis. Gas engine.
455,388. July 7, 1891. Charter. Gas engine.
*456,284. July 21, 1891. Coffield et al. Gas engine.
460,070. Sept. 22, 1891. Hobbs. Rotary gas engine.
*482,202. Sept. 6, 1892. Schumm. Gas or oil motor engine.
498,700. May 30, 1893. Walls. Gas engine.
506,817. Oct. 17, 1893. Hobbs. Gas engine.
511,535. Dec. 26, 1893. Lewis. Gas engine.
511,855. Jan. 2, 1894. Mann. Electrohydrocarbon engine.
522,712. July 10, 1894. Hirsch. Gas engine.
*523,511. July 24, 1894. Campell. Oil engine.
525,651. Sept. 4, 1894. Grant. Gas engine.
*525,857. Sept. 11, 1894. McGeorge. Gas engine.
532,099. Jan. 8, 1895. Robinson. Gas or vapor and air mixing and spraying device.
*532,100. Jan. 8, 1895. Robinson. Vaporizing and ignition device.
532,412. Jan. 8, 1895. Bilbault. Gas or petroleum engine.
*534,354. Feb. 19, 1895. Weber. Gas engine.
536,029. Mar. 19, 1895. Gill. Gas engine.
537,253. Apr. 9, 1895. Van Zandt. Gas engine.
*537,370. Apr. 9, 1895. Walls. Gas engine.
*539,710. May 21, 1895. Sintz. Gas engine.
541,773. June 25, 1895. Mead. Gas engine.
543,094. July 23, 1895. Hopkins. Motor for bicycles.
*548,922. Oct. 29, 1895. Norman. Gas and oil engine.
550,163. Nov. 19, 1895. Durand. Compressed-air motor.
550,266. Nov. 26, 1895. Froelich. Gas engine.
*550,451. Nov. 26, 1895. Lanson et al. Gas engine.
*550,785. Dec. 3, 1895. Friend. Hydrocarbon motor.
555,373. Feb. 25, 1896. Henriod-Schweizer. Petroleum motor.
560,149. May 12, 1896. Rober. Vapor engine.
562,230. June 16, 1896. Mex. Petroleum motor.
563,249. July 7, 1896. Baker. Gas engine.
564,576. July 21, 1896. Altham. Oil engine.
564,577. July 21, 1896. Altham. Oil engine.
565,786. Aug. 11, 1896. Olds et al. Gas or vapor engine.
569,530. Oct. 13, 1896. Winter. Gas engine.
571,534. Nov. 17, 1896. Lewis. Gas engine.
*574,183. Dec. 29, 1896. Underwood. Mixer for gas engines.
574,535. Jan. 5, 1897. Grohmann. Gas engine.
579,554. Mar. 23, 1897. Blum. Gas motor.
582,108. May 4, 1897. Winton. Explosive engine.
*584,666. June 15, 1897. Bollée. Motor vehicle.
*588,466. Aug. 17, 1897. Pace. Combustion engine.
*595,043. Dec. 7, 1897. Chase. Gas engine.
*595,552. Dec. 14, 1897. Banki et al. Gasoline motor.
*596,809. Jan. 4, 1898. Guyer. Gas engine.

597,389. Jan. 18, 1898. Bullis. Gasoline engine.
598,025. Jan. 25, 1898. Simark. Gas engine.
599,235. Feb. 15, 1898. Hider. Explosive engine.
*599,375. Feb. 22, 1898. White. Gas engine.
*599,376. Feb. 22, 1898. White. Gas-engine attachment.
*600,147. Mar. 8, 1898. Halvorson. Explosive engine.
602,556. Apr. 19, 1898. Dayle. Gas or gasoline engine.
603,318. May 3, 1898. Clover. Oil gas motor.
*603,986. May 10, 1898. Henriod. Explosive engine.
*608,968. Aug. 8, 1898. Morava. Gas or oil motor for bicycles.
*610,460. Sept. 6, 1898. Petrot. Self-propelling carriage.
615,978. Dec. 13, 1898. Fielding. Internal-combustion motor.
617,022. Jan. 3, 1899. Irgens et al. Means for converting heat into motoric force.
618,972. Feb. 7, 1899. Alsop. Gas engines.
*619,776. Feb. 21, 1899. Murray. Gas engine.
620,602. Mar. 7, 1899. Maxim. Explosive engine.
622,798. Nov. 11, 1899. Fagerstrom. Regulating device for petroleum motor.
623,567. Apr. 25, 1899. Secor. Speed regulator for explosive engines.
*624,594. May 9, 1899. Wilkinson. Motive-power mechanism.
*626,121. May 30, 1899. Winton. Speed regulator for explosive engine.
*627,219. June 20, 1899. Woolf. Air and gas engine.
*627,359. June 20, 1899. Steele. Automobile vehicle.
632,474. Sept. 5, 1899. Sangster. Motor-driven vehicle.
*632,917. Sept. 12, 1899. Dallenbach. Explosive engine.
*635,218. Oct. 17, 1899. Winton. Oil valve for gasoline engine.
*636,048. Oct. 31, 1899. Korsmeyer. Gasoline or gas engine.
638,331. Dec. 5, 1899. Grant. Motor vehicle.
*640,394. Jan. 2, 1900. Lewis. Gas engine.
*640,674. Jan. 2, 1900. Lewis. Explosive engine.
640,890. Jan. 9, 1900. Eisenburth. Air and gas engine.
641,727. Jan. 23, 1900. Robertson et al. Gasoline engine.
652,544. June 26, 1900. Miller. Gas engine.
*658,127. Sept. 18, 1900. Simmonds. Gas or gasoline engine.
*658,367. Sept. 25, 1900. Haynes et al. Explosive engine.
660,129. Oct. 23, 1900. Standish. Rotary explosive motor.
662,169. Nov. 20, 1900. Gender. Engine operated by fluid under pressure.
667,908. Feb. 12, 1901. Hatcher. Speed regulator for explosive engine.
*670,803. Mar. 26, 1901. McMahon. Gas engine.
673,109. Apr. 30, 1901. Brouder. Gas engine.
673,110. Apr. 30, 1901. Bronder. Motor vehicle.
681,287. Aug. 27, 1901. Worth. Speed regulator for explosive engines.
*682,606. Sept. 12, 1901. Duryea. Explosive engine for motor vehicle.
*682,682. Sept. 17, 1901. Hafelfinger. Motor bicycle.
*684,011. Oct. 8, 1901. Valentynowicz. Explosive engine.
685,722. Oct. 29, 1901. Marrder. Rotary explosive engine.
*690,481. Jan. 7, 1902. Sweet. Explosive engine.
702,374. June 10, 1902. McCall. Air superheater or carburetor.
703,511. July 1, 1902. Wood. Oil vapor engine.
706,711. Aug. 12, 1902. Andres. Multiple-cylinder explosive engine.
707,793. Aug. 26, 1902. McKaig. Gasoline engine.
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REPORT NO. 11.

PART III.

NEW CLASSIFICATION AND ASSIGNMENT OF CARBURETORS.

By Charles E. Lucke.

**) NEW CLASSIFICATION OF CARBURETORS OF THE PROPOR-
'IONING-FLOW TYPE ON A RATIONAL BASIS OF SIMILARITIES
ND DIFFERENCES, BOTH OF STRUCTURAL AND FUNCTIONAL
)PERATIONS.**

'hose cases appearing in the four official lists of carburetor patents t upon examination are found to be proportioning-flow car- etors are marked with an asterisk [*], and these are rearranged e according to the new basis of classification, which provides 15 sses and 61 subclasses. The distinction between one class and an- er is indicated in Table I, which serves as a general guide to the lowing list of definitions of the new general classes and the several classes under each. In general the distinction between the classes based on the constancy or variability of the area of the fuel and flow passages, with reference to flow rate. Any such passage t does not automatically vary with flow rate is regarded as fixed, n though a manual adjustment is provided; in this case the area djustably fixed. It is necessary for the condition of variable area t the passage be provided with a regulating valve which graduates area with reference to flow, and such a valve acting as, or con- ted to, a throttle, is regarded as automatic, as well as when inde- dent of the throttle and actuated automatically by the flow itself.

Table I.—*Guide to new classification of proportioning-flow carburetors.*

s.	Subclasses.	Fuel inlet.	Air inlet.
...	1.1, 1.2, 1.3, 1.4	Fixed, with periodic stop valve	Fixed.
...		Fixed from pump	Fixed, with air-motor driving pump.
...	3.1, 3.2, 3.3, 3.4, 3.5	Single, fixed	Single, fixed.
...	4.1	....do	Multiple, fixed.
...	5.1, 5.2, 5.3	Multiple, fixed	Single, fixed.
...	6.1, 6.2, 6.3, 6.4, 6.5, 6.6	....do	Multiple, fixed.
...	7.1, 7.2, 7.3, 7.4, 7.5	Single, fixed	Single, variable with regulating valve.
...	8.1, 8.2, 8.3, 8.4, 8.5, 8.6	....do	Multiple, variable with regulating valve.
...	9.1, 9.2, 9.3, 9.4, 9.5	Multiple, fixed	Single, variable with regulating valve.
...	10.1, 10.2, 10.3, 10.4, 10.5, 10.6, 10.7, 10.8.	....do	Multiple, variable with regulating valve.
...	11.1, 11.2, 11.3, 11.4	Single, variable with regulating valve.	Single, fixed.
		....do	Multiple, fixed.
		Multiple, variable with regulating valve.	Single, fixed.
		....do	Multiple, fixed.

TABLE I.—*Guide to new classification of proportioning-flow carburetors*—Contd.

Class.	Subclasses.	Fuel inlet.	Air inlet.
12......	12.1, 12.2, 12.3, 12.4, 12.5, 12.6, 12.7.	Single, variable with regulating valve.	Single, variable with regulating valve.
13......	13.1, 13.2, 13.3, 13.4, 13.5, 13.6.	.....do........................	Multiple, variable with regulating valve.
14......	14.1, 14.2.............	Single, variable with regulating valve.	Single, variable with regulating valve.
		Multiple, variable with regulating valve.	Multiple, variable with regulating valve.
15......	15.1, 15.2.............	Variable thermostatically..	Variable thermostatically, barometrically.

PROPORTIONING FLOW CARBURETORS—NEW CLASSES AND SUBCLASSES.

NEW CLASS 1.—CARBURETORS, PROPORTIONING FLOW, FIXED AIR AND FUEL INLETS, PERIODIC FUEL VALVE.

Includes all cases of a single fuel inlet with a fuel valve opened each suction stroke without graduation of movement; single or double air inlet with a similarly operated valve or no air valve at all. Both the air and the fuel passages are of constant area when open. Normally designed for pressure supplies of fuel and for slow speed engines, more particularly those of the hit-and-miss governed stationary type, but not to the exclusion of others. Fixed area does not exclude manually adjusted air or fuel openings or the valves to make such adjustments because they do not change flow area with flow rate.

New subclass 1.1—Mechanically operated fuel valve, single air inlet.—The engine valve gear operates the fuel valve with, or without, an air inlet valve, in synchronism with the engine inlet valve, by direct mechanical movement or indirectly as, for example, by making electrical contacts to energize a solenoid.

New subclass 1.2—Single air inlet with automatic valve, fuel inlet in seat.—Single air inlet fitted with an automatic valve closed by gravity or a spring, and opened by the air flow or vacuum of disk, swing or other type, lifting substantially the same amount and exposing the fuel inlet completely, each time it lifts. The vacuum beyond the air valve has little or no influence on the fuel flow.

New subclass 1.3—Single air inlet automatic valve, fuel inlet beyond.—The lifting resistance of the automatic valve results in a vacuum beyond it, which directly influences fuel flow.

New subclass 1.4—Double air inlet, primary and secondary.—Air enters at two points, the primary directly sweeping the point of fuel inlet and exerting its velocity head influence on fuel flow, the secondary entering elsewhere and normally through a manually adjustable opening.

New class 2—Carburetors proportioning flow, metering fuel pump air motor driven.—All types of air motor operated by the air that is being drawn into the engine by its piston suction, driving directly a fuel pump, when the air motor and the fuel pump are equivalent to two volume meters, the former driving the latter. Excluding fuel pumps operated by pressure pulsations of the air as not essentially related to the volume of air passing, and also all engine-driven fuel pumps with air fans or compressors as not essentially proportioning

New class 3—Carburetors, proportioning flow, aspirating, single fixed fuel and air inlets.—All cases of fuel and air inlets not provided with graduating valves, but allowing manual adjustments, where the fuel enters only because of a depression of air pressure caused by the air flow as a result of the air velocity head, or of the entrance resistance or both. Single inlet for air includes a series of holes as equivalent to a slot when all the air flows and acts in the same way. Fuel inlets are single even when branched or of several orifices, if all are located in the same vacuum and act together. In all cases "aspirating" implies that the fuel is taken from a cup normally, but not always of constant level type, open to the atmosphere, the level in which is below that of the fuel inlet. The arrangement is always such that there is no fuel flow until the flow of air causes a lowering of pressure at the fuel outlet.

New subclass 3.1—Fuel inlet at air throat.—Air passages more or less regularly tapering toward a minimum area section or throat and later expanding, of which the venturi tube is the type form, and often called in the less perfect forms, "choke" or "strangle" tubes, with the fuel inlet at or near the throat. Such passages may be curved as well as straight. Normally the reduction of pressure inducing fuel flow is wholly due to air velocity head, and not at all to entrance resistance, but not exclusively so.

New subclass 3.2—Air guides or baffles.—After or during entrance, the air is guided so as to sweep the point of fuel entrance to produce an air velocity head vacuum effect on fuel flow, positively or negatively, if such positive action tends otherwise to become too vigorous.

New subclass 3.3—Rotating fuel spreader, air driven.—Movement of the air causes an air motor, usually constructed like a fan to rotate, and the fuel is discharged directly on the vanes or on a separate plate driven by them. The rotation may aid in fuel discharge by centrifugal action, but the fuel flow is primarily due to the vacuum at the outlet, otherwise the case would come under class 2.

New subclass 3.4—Variable jet and throat relation.—Air passages normally tapered to form a throat and the fuel inlet located at the end of a nozzle. Either air throat or fuel nozzle may be fixed in position while the other moves under the influence of the air flow, but without changing the flow area of either the air or the fuel passage. The effect is to change the velocity head at the fuel outlet with flow, usually automatically, from what it would be if the fuel outlet remained at a fixed point with reference to the throat.

New subclass 3.5—Variable float chamber pressure.—Fuel is taken from a closed cup or chamber, fitted with a valve, float, or diaphragm controlled for level, but the pressure on the chamber, instead of being constant atmospheric or otherwise, is varied, sometimes increased to induce a greater fuel flow, and sometimes decreased to retard an excess fuel flow. In some cases a small air flow through this chamber is used to secure the pressure control desired, but this is not considered as air flow in the ordinary sense because the quantity is negligible.

New class 4—Carburetors, proportioning flow aspirating, single fuel, multiple air inlets, both fixed.—Two or more air inlets, all fixed or adjustably fixed in area, which can be grouped in two ways. The first grouping is into primary and secondary, the former in-

cluding all air that sweeps the fuel inlet and adds by its velocity head some vacuum to induce fuel flow to the entrance resistance of both primary and secondary air; secondary air being that which enters beyond or by-passes the fuel inlet, and, therefore, has little or no aspirating effect on the fuel by its velocity head. Cases of this sort are classed here. The second grouping is into plain and mixed flow air passages, each with its own inlet, and such cases are classed under subclass 4.1.

New subclass 4.1—Mixed flow.—Part of the air, usually a small amount, enters the fuel passage, relieving the vacuum otherwise acting on the fuel at that point and thereby affecting its flow. Beyond the point of air entrance into the fuel passage both this air and the fuel move together to the fuel inlet constituting mixed flow. This mixed-flow air entrance may be active through the whole range of the carburetor-flow rates or only during the high-flow rate periods—i. e., continuous or intermittent.

New class 5—Carburetors, proportioning flow, aspirating, multiple fuel, single air inlets, both fixed.—Fuel inlets are multiple when they are differently situated for fuel flow at different heights above the level of the constant level chamber in regions of equal vacuum, or at the same heights in regions of different vacuum, or both, regardless of the number of actual orifices. Being fixed, they are without valves for graduating or regulating flow, though stop valves may be present, or manually adjusted valves or periodic opening valves, as in class 1. All the fuel inlets need not work continuously; some may act intermittently at some particular flow rate.

New subclass 5.1—Main fuel inlet, with supplementary high-speed jet.—One or more of the fuel inlets act throughout the whole range of air flow or mixing-chamber vacuum, while another one or set of fuel inlets will come into action when the vacuum is high, due to high rates of air flow, and is therefore intermittent.

New subclass 5.2—Main fuel inlet, with supplementary idling jet.—The supplementary jet acts only when the throttle is closed and is out of action when the throttle is wide open or the air-flow rate high. The main fuel inlet acts throughout the entire range of air-flow rates except perhaps on closed throttle, when it may go out of action, being replaced by the idling jet.

New subclass 5.3—Fuel standpipes.—A tube with holes at different heights above the level in the constant level chamber serves as the fuel inlet, or there may be separate tubes with outlets placed correspondingly. Increase of vacuum in the mixing chamber, due to increased air flow, causes the fuel to rise to successively new and high orifices, the fuel flow increasing correspondingly.

New class 6—Carburetors, proportioning flow, aspirating, multiple fuel and multiple air inlets, both fixed.—More than one fuel inlet differently situated for flow, and more than one air inlet also different in position or action, the several inlets acting continuously, or intermittently by succession or alternation.

New subclass 6.1—Double carburetor, progressive, by throttle.—Two complete carburetors each with its own fixed fuel and air inlets one working throughout the whole range, the other being brought into action by the throttle as it approaches full open position.

New subclass 6.2—Multiple carburetor, progressive, by throttle.—More than two complete carburetors, each with its own fixed fuel and air inlets, one always in action and the others brought in successively as the throttle is opened.

New subclass 6.3—Double carburetor, progressive, by vacuum.—Two complete carburetors, as in class 6.1, but the second brought into action by the vacuum acting on a piston, disk, or diaphragm, when the air flow in the first becomes high enough to result in a vacuum in excess of a predetermined value.

New subclass 6.4—Multiple carburetor, progressive, by vacuum.—More than two complete carburetors, each with its own fixed air and fuel inlets, one always in action and the others brought in successively by the vacuum.

New subclass 6.5—Mixed flow.—Part of the air enters one or more of the fuel passages thereby affecting the fuel flow. This mixed flow action may be continuous or intermittent and may affect all the fuel inlets or only one. When intermittent, the mixed flow may act on one of the main fuel jets to modify its flow at high rates, or at low rates due to closed throttle may act as a jet, or both. Two fuel inlets, side by side, are multiple when one discharges fuel only while the other discharges fuel and air, even though the jets are in the same vacuum because this vacuum does not act equally in producing fuel flow in both.

New subclass 6.6—Fuel standpipe.—Multiple orifices in a standpipe at different levels, or multiple passages with outlets at different levels coming successively into action as the vacuum increases, receiving primary air from one or one set of air inlets, secondary air entering beyond from others.

New class 7—Carburetors, proportioning flow, aspirating, single fixed inlet and single air inlet with regulating valve.—A fixed fuel inlet is associated with one air inlet provided with a valve for graduating the air-inlet area as flow changes, so that for any given flow rate the vacuum acting on the fuel inlet and inducing fuel flow is not the same as it would be with a fixed air inlet. The vacuum is, therefore, not merely the result of a given rate of air flow, but depends just as much, or more, on the air-inlet area as regulated by the air valve. This air valve may be actuated in any way or be of any form, each type combination constituting a subclass. There may be more than one fuel inlet, but if all are so located as to work similarly as to fuel flow versus air vacuum they must be regarded as a multi-branched single inlet, even if supplied with different fuels, so far as proportioning is concerned.

New subclass 7.1—Fuel inlet between throttle-controlled air valve and throttle.—As the throttle or mixture outlet valve is moved the air-inlet valve moves with it, thereby controlling to some extent the vacuum between them which acts on the fuel flow. The connection may be by simple linkage or by special cams to secure any desired relative change in the areas of the air inlet and the throttle outlet.

New subclass 7.2—Fuel inlet at or before air valve which acts as a throttle.—Placing the fuel inlet in the air entrance, fuel flow is induced entirely, or substantially so, by the velocity head of the air, and this velocity head is regulated by the air valve. In such cases no separate throttle is necessary; the air valve itself may be regarded as the throttle and called such instead of air valve.

New subclass 7.3—Fuel inlet between automatic air valve and throttle.—Air enters through an automatic air valve of any form, opened by the vacuum against a spring or gravity closing load, and the vacuum which acts on the fuel inlet is controlled by the size form and loading of this automatic valve. The automatic air-inlet valve may close the air entrance completely or there may be some fixed air inlets nearby. If the air from such fixed air inlet moves with the air from the automatic valve, the effect is substantially the same as if all the air entered through the automatic valve, which still is the controlling element in the fuel-flow vacuum. When part of the air enters through a fixed and part through an automatic valved inlet, one acting as primary and the other as secondary air, the case falls under subclass 8.2.

New subclass 7.4—Fuel inlet swept by air entering through automatic air valve.—This subclass differs from the last in the position of the fuel inlet with relation to the air inlet. Here the fuel inlet is so located as to be directly swept by the entering air, fuel flow being largely dependent on the air-velocity head. Normally the automatic air valves of this subclass are but lightly loaded or the lead does not increase fast enough with flow, and there is insufficient air-entrance resistance to alone produce the vacuum required to draw enough fuel. The automatic valve need not completely close the air inlet; there may be fixed air inlets nearby; but no combination that could be regarded as divisible into primary and secondary air is permissible in the subclass.

New subclass 7.5—Variable float chamber pressure.—Fuel is taken from a closed chamber fitted with a level control valve, but the pressure in the chamber is varied by connection to the carburetor interior to control the flow of fuel from the single fixed inlet, in addition to such control as might be available with the variable air inlet. A small air flow through the float chamber used solely to secure the desired pressure on the surface of the fuel is not regarded as air flow in the general sense.

New class 8—Carburetors, proportioning flow, aspirating, single fixed fuel inlet, multiple air inlets, valved for regulation.—The air enters at more than one point, the entrance locations being such that their aid does not act the same in inducing fuel flow. The difference may be that corresponding to primary versus secondary air or main versus mixed-flow air. At least one of the air inlets has a regulating valve operated automatically or by the throttle, and the others may be fixed or themselves fitted with regulating valves.

New subclass 8.1—Two air inlets, fixed primary, throttle controlled secondary regulating air valve.—A fixed air passage carries a fixed fuel jet and beyond it secondary air is admitted through a port controlled directly by the throttle itself or by a separate valve linked to the throttle. The secondary air may enter at all throttle positions or be cut off when throttle is nearly closed.

New subclass 8.2—Two air inlets, fixed primary, automatic secondary regulating air valve.—To the mixture formed from the fixed fuel and primary air inlets secondary air is added through an automatic valve, which opens when the vacuum exceeds its closing load. The automatic valve need not completely close the secondary air inlet. There may be fixed inlets near by, but it does control the final

vacuum and total amount after it opens. Similarly the primary air may leave more than one orifice.

New subclass 8.3—Two air inlets, both with regulating valves, one automatic, the other throttle controlled.—Primary air may enter through the automatic and the secondary air through the throttle controlled valve or vice versa. As in other cases, the regulating air valve need not completely close the air inlet it controls, and may be of multiorifice form.

New subclass 8.4—Two air inlets, both with automatic-regulating valves.—Both primary and secondary air enter through automatic valves, which may be entirely separate and similar or different in form, size, or loading, or there may be one ordinary automatic valve, with a linkage connection controlling another valve entirely different. In all cases it is the vacuum that controls not only the whole air but the relative amounts of primary and secondary, either directly or indirectly automatically and independent of the throttle.

New subclass 8.5—Two air inlets, both with throttle-controlled regulating valves.—There may be three valves, two for air inlet and a third acting as throttle, or only two, the two air inlets moving together and acting as throttle; but in both cases the primary and secondary air are controlled in ratio as well as total quantity by mechanically operated valves acting as throttle or connected to it.

New subclass 8.6—Mixed flow.—Part of the air enters the fuel passage, affecting the fuel flow and emerging with the fuel from the fuel inlet either continuously or intermittently. The other air stream, or main air, may enter in any of the ways appropriate to the class, through one or more inlets with regulating valves. Normally the mixed-flow air inlet has no valve except as a liquid seal may act as a stop valve, but a regulating valve may be added.

New class 9—Carburetors, proportioning flow, aspirating, multiple fixed fuel inlets, single air inlet with regulating valve.—A series of fuel inlets without regulating valves are so disposed as to be acted upon differently by the air which enters through a single valve regulating the air-inlet area. The fuel inlets may be located in the same position or vacuum region and arranged to be brought into action successively as the air-inlet area increases, or they may be arranged at different levels in the same chamber, to be brought into action as the vacuum causes the level to rise, or they may be located in different places in the chamber where the vacuum is different.

New subclass 9.1—Fuel inlets act progressively with opening of single automatic air-inlet regulating valve.—Air enters through a port controlled by an automatic valve, spring or gravity loaded, usually the former, and opened by the vacuum. As the effective size of the air inlet increases, the fuel inlets are brought into action successively as the air sweeps past an increasing number. Fuel flow is induced primarily by the air-velocity head past each fuel inlet in turn, though not exclusively so, and the fuel inlets are located at or before the air inlet.

New subclass 9.2—Fuel inlets act progressively with opening of single throttle-controlled air-inlet regulating valve, or air valve acting as throttle.—Instead of moving automatically, as in the last subclass, the air valve is here controlled by the throttle or is itself the throttle, otherwise there is no difference.

New subclass 9.3—Fuel standpipe.—Single tubes with holes, or a series of tubes with outlets, successively higher, arranged in a chamber supplied with air from an air inlet having a regulating valve, either automatic or throttle controlled.

New subclass 9.4—Two fuel inlets, one main and one idling.—A main fixed fuel inlet is disposed between the automatic valved air inlet and the throttle, with a supplementary fuel inlet located so as to be brought into action when the throttle is closed, or nearly so. Two fuel inlets may be similarly arranged for the main and supplemental low speed or idling action, associated with an air-inlet regulating valve, throttle controlled, or acting as throttle, in which case one or both of the fuel inlets may be at or in front of the air.

New subclass 9.5—Tilting fuel chamber, radially disposed fuel inlets.—Either the float chamber itself or a supplemental chamber connected with it, in which the fuel level is under control, lies wholly within the air passage, and arranged to be tilted or partially rotated so as to bring into action successively a series of fuel inlets disposed about its axis. The tilting is accomplished by a connection with the throttle, and the chamber itself may act as air-regulating valve, or as both throttle and air valve.

New class 10—Carburetors, proportioning flow, aspirating, multiple fixed fuel inlets with air inlets, valved for regulation.—Multiple, applied as ter, to fuel inlets implies that the several inlets shall be at least in part subjected to different fuel flow conditions, and either regularly, intermittently, or successively have imposed upon them more or less different conditions; mere multiplicity of orifices is not intended. The term multiple applied to air inlets has a similar significance, the several air inlets either act differently at the same time, or act in succession or alternately. At least one of the air inlets has a regulating inlet valve, controlled by the throttle or acting as throttle, or automatic, and all the inlets may be similarly valved.

New subclass 10.1—Main fuel inlet, with supplementary high-speed jet.—Two fuel inlets, both fixed, one the main or low-speed jet, acting constantly, and the other a supplementary or high-speed jet, brought into action at high-flow rates by the vacuum, by the opening of a secondary automatic air valve. Normally the main jet is located in a fixed air inlet and there is an automatic secondary air valve, through other air-inlet arrangements are included, provided one at least has a regulating valve.

New subclass 10.2—Main fuel inlet, with supplementary idling jet.—Two fuel inlets, both fixed, one the main or high-speed jet acting constantly except perhaps at low rates or closed throttle, the other a supplementary idling jet brought into action by the throttle in its closed or nearly closed position and normally replacing the main jets for low-flow rates. In all cases there is more than one air inlet and at least one of them has an automatic regulating valve; the normal case is that of one fixed primary or main air and an automatic secondary.

New subclass 10.3—Multiple carburetor, progressive, by throttle, with individual automatic air-inlet regulating valves.—Two or more fixed fuel inlets, each located in a separate air passage, supplied through an automatic air-inlet valve, brought into action in succession by the throttle. The automatic air-inlet valves may or may not

completely close the air inlets, but even if there are near by fixed air inlets, the automatic valves control the air flow and the vacuum at the fuel outlet when they open. There may be a secondary air inlet for each jet or a common one for all or none at all.

New subclass 10.4.—Multiple carburetor, progressive, by vacuum, with individual automatic air-inlet regulating valves.—This subclass is similar to the last, except that the progressive acting of the several similar members is controlled by an automatic valve, vacuum moved, at their outlets.

New subclass 10.5—Fuel standpipe.—Fuel rises with increase of vacuum successively higher outlets in a single standpipe or in separate tubes, located in a fixed primary air passage, secondary air entering through an automatic valve in a separate air-inlet passage.

New subclass 10.6—Mixed flow.—Part of the air enters one or more of the fuel passages affecting the fuel flow in it and making it a mixed flow passage, either steadily or intermittently, the fuel likewise flowing from its several inlets either steadily or intermittently. When the action of the air into a mixed flow passage, or that of the fuel through an inlet, is intermittent, this may be due to throttle position or to vacuum or both.

New class 11—Carburetors, proportioning flow, aspirating, single or multiple fuel inlets with regulating valves, single or multiple fixed air inlet.—Fixed air inlets are associated with fuel inlets provided with fuel-regulating valves in any number, from one fixed air and one regulated variable fuel upward. The fuel-regulating valve may be actuated by a throttle connection or by the vacuum or by the air flow directly.

New subclass 11.1—Single fuel-inlet valve, throttle controlled.—To a fixed air passage the single fuel inlet is connected in any of the ways already classified for fixed fuel inlets, but here the fuel inlet is provided with a regulating valve connected to and moving with the throttle, so that fuel flow no longer varies primarily as a result of a change in the air vacuum, but also directly as a result of the area made available for its flow by the fuel-regulating valve. A secondary fixed air passage may be present.

New subclass 11.2—Single fuel inlet, independently controlled by air flow or vacuum.—One fuel inlet with a graduating valve directly actuated by the vacuum or by the air flow acting by impact on a moving member or lifting a flow valve, without affecting the air inlet area up to the point of fuel inlet. There may be a fixed secondary air passage.

New subclass 11.3—Mixed flow.—One or more fuel inlets, at least one with a fuel regulating valve actuated in any way. Two or more air inlets, at least one of which enters the fuel passage affecting its flow and making it from that point on a mixed flow passage.

New class 12—Carburetors, proportioning flow, aspirating, single fuel and air inlets, both with regulating valves.—Regulating valves are provided to control the areas of both the single air and fuel inlets, so proportionality becomes as much a matter of the relative areas of two variable inlets as of the vacuum at the fuel inlet that results from the air flow.

New subclass 12.1—Valved fuel inlet beyond air inlet valve acting as throttle, fuel valve controlled by air valve.—A direct connection

between the fuel and the air inlet valve controls the total quantity of air and fuel and the ratio by inlet areas alone. The fuel inlet is in a region where the vacuum is that due to the air flow through the restricted valved inlet.

New subclass 12.2—Valved fuel inlet between air inlet valve and throttle, both fuel and air valves controlled by the throttle.—By using a throttle in addition to an air valve the vaccum between them is under control, and by it the fuel flow also, independent of such fuel flow control as results directly from the fuel regulating valve linked to both throttle and air valve.

New subclass 12.3—Valved fuel inlet, at or in front of air valve acting as throttle, fuel valve controlled by air valve.—Locating the fuel inlet at, or in front of the air valve opening relieves it of the vacuum beyond, and the fuel flow is normally though not exclusively the result of air velocity head at the entrance, the fuel area being graduated to correct excesses or deficiencies of fuel flow otherwise present.

New subclass 12.4—Valved fuel inlet between automatic air inlet valve and throttle, fuel valve controlled by throttle.—Air entrance through an automatic valve results in a limited variation of vacuum at the point of fuel inlet affecting fuel flow, which is also subject to the variations of fuel inlet area resulting from the control of the fuel valve by the throttle. The automatic air inlet valve may or may not close the inlet completely, but it controls the air flow and vacuum even if some fixed air inlets are located nearby.

New subclass 12.5—Valved fuel inlet between automatic air-inlet valve and throttle, fuel valve controlled by automatic air valve.—As in the last case the fuel inlet is subjected to the entrance resistance of the air passing the automatic valve and the fuel flow is the result, partly of this and partly of the change in the fuel inlet area as regulated by the fuel valve which is here actuated by automatic valve. Normally both air and fuel are primarily controlled in quantity and proportion by the two relative and connected valved openings rather than by any material vacuum change, though not exclusively. The automatic air valve need not completely close the air inlet.

New subclass 12.6—Valved fuel inlet, between air inlet valve and throttle, fuel valve vontrolled independently by vacuum or air flow.—The air inlet valve may be either sort, automatic or mechanically connected to throttle, but the fuel valve is controlled independently of the air valve or throttle, by the vacuum directly, or by flow valves beyond it, or by air impact on moving members.

New subclass 12.7—Variable float chamber pressure.—In addition to the use of a fuel inlet with a regulating valve associated with an air inlet similarly provided with a regulating valve, fuel flow is subjected to the further control of the pressure in a closed float chamber which is varied by a connection to the vacuum chamber of the carburetor. Any air that flows through the float chamber as part of the means of pressure control on the fuel surface is disregarded.

New class 13—Carburetors, proportioning flow, aspirating, single fuel and multiple air inlets, both with regulating valves.—Normally, two air inlets, one primary and the other secondary, are associated with a single fuel inlet having a regulating valve, but there may be more air inlets.

New subclass 13.1—Valved fuel inlet, fixed primary air, fixed or valved secondary air inlet, throttle control of fuel-inlet valve and of secondary air valve.—The changes in vacuum at the fuel inlet supplied with primary air from the fixed air inlet, even as modified by a fixed or throttle-controlled secondary air, are not relied upon to control fuel flow, but a fuel-regulating valve actuated by the throttle is added.

New subclass 13.2—Valved fuel inlet, valved primary and secondary air inlets, throttle control of both air inlets and fuel-inlet valve.—Variation of two air-inlet areas and the fuel-inlet area with the throttle subjects both air and fuel flow to the control of mechanically related inlet and throttle outlet areas, and the vacuum at the fuel outlet still remains as a factor.

New subclass 13.3—Valved fuel inlet, fixed primary and throttle-controlled secondary air inlets, fuel valve controlled by the vacuum or air flow independently.—Fuel-inlet area is dependent upon the vacuum or air-flow conditions independent of the throttle or of the throttle-controlled secondary air.

New subclass 13.4—Valved fuel inlet, fixed primary and automatic valved secondary air inlets, fuel valve controlled by the throttle.—Fuel-inlet area is dependent upon the mixture-outlet area by the throttle connection and is independent of the air-inlet areas, the vacuum at the fuel inlet being, however, directly dependent on the air inlets.

New subclass 13.5—Valved fuel inlet, fixed primary and automatic valved secondary air inlets, fuel valve controlled by the automatic secondary air valve.—The throttle is independent. Fuel-inlet area is related to the movement or entrance area of the automatic secondary valve.

New subclass 13.6—Valved fuel inlet, valved primary and secondary air, both automatic, fuel valve controlled by one or both automatic air-inlet valves.—The two air-inlet automatic valves may be independent or consist of two ports controlled by one valve, and the inlets need not be completely closed by the automatic valves so long as they control the flow and the resulting vacuum.

New class 14—Carburetors, proportioning flow, aspirating, multiple fuel and air inlets, both with regulating valves.—Two or more fuel inlets each differently situated or different in action are associated with two or more fuel inlets each acting differently with respect to flow, and at least one of the fuel and one of the air inlets is provided with a regulating valve, though all may be so equipped.

New subclass 14.1—Two fuel inlets, one fixed main and one valved supplementary high-speed jet, two air inlets, one fixed primary and one valved secondary.—A two-jet type of carburetor, the second or high-speed jet coming into action with the opening of the secondary air valve automatically or brought in by the vacuum due to high-flow rates. However brought in, the high-speed jet is provided with a regulating valve.

New subclass 14.2—Multiple carburetors, progressive by throttle or vacuum.—Two or more complete carburetors, each with its own fuel and air inlet, both with regulating valves, and brought successively into action by either the throttle or the vacuum. There may be a common secondary air inlet at their outlets, throttle controlled or automatic.

New class 15—Carburetors, proportioning flow, aspirating, thermostatic or barometric control.—Density corrections for air or fuel, and for viscosity of fuel to compensate for changes in temperature of either, or changes in absolute pressure of the former, by actuating their inlet valves or by restoring the original value of the variable.

New subclass 15.1—Thermostatic controls.—Automatic means of keeping a constant temperature of air or fuel or both or of actuating the regulating valves to compensate for temperature changes.

New subclass 15.2—Barometric controls.—Automatic means of keeping the absolute pressure of the air supply constant or of actuating the air-inlet valves to compensate for variations.

(B) Assignment to the new classes and subclasses of all United States patents for "proportioning-flow" type carburetors found in the official lists of Part II (A), (B), (C) and (D), constituting a new list of all United States patents containing proportioning-flow carburetors arranged according to the new classification.

United States patents.

Patent No.	Present official— Class.	Present official— Subclass.
New class 1, carburetors, proportioning-flow fixed air and fuel inlets, periodic fuel valve:		
517,344	123	130
531,779	48	149
532,314	123	28
534,354	C. R. 2	....
556,069	48	154.1
565,033	123	35
566,125	123	35
578,034	123	35
581,930	48	155
584,666	C. R. 2	....
587,627	C. R.	....
598,832	123	129
599,375	C. R. 2	....
599,376	123	112
608,968	C. R. 2	....
611,341	48	134.1
614,114	123	123
627,359	C. R. 2	....
632,859	C. R.	....
635,298	261	51
	123	133
630,048	C. R. 2	....
649,191	48	154.1
657,140	C. R.	....
658,127	C. R. 2	....
658,367	C. R. 2	....
668,953	261	13
670,921	48	154.1
680,115	123	119
682,682	C. R. 2	....
688,367	48	154.1
692,444	261	67
696,231	48	148
703,937	48	154.1
705,314	48	155
705,021	48	148
722,672	123	123
706,050	48	155
714,982	48	154.1
724,328	48	154.1
725,191	123	35
727,476	48	154.1
729,254	48	154.1
730,608	48	154.1
741,959	48	154.1
New class 1, carburetors, proportioning-flow fixed air and fuel inlets, periodic fuel valve—Continued.		
747,235	48	154.1
748,990	123	129
756,879	48	150.1
760,333	C. R. 2	....
760,673	48	154.1
761,192	48	155
761,392	48	154.1
778,154	C. R. 2	....
778,988	48	148
791,192	48	154.1
793,498	48	155
794,192	123	123
806,079	48	154.1
811,397	261	62
817,051	261	12
820,408	48	154.1
826,787	48	154.1
842,429	48	154.1
850,223	48	154.1
860,630	123	35
863,516	C. R.	....
866,002	C. R. 2	....
868,265	48	155.2
871,288	48	150.1
878,824	48	155
890,099	48	154.1
891,322	48	150.2
911,967	48	154.1
915,684	48	154.1
930,483	C. R.	....
944,811	48	154.1
955,222	48	154.1
973,882	48	154.1
974,033	48	154.1
975,696	C. R.	....
976,409	48	155.1
978,076	48	154.1
994,886	48	154.1
979,409	48	154.1
999,033	48	154.1
999,687	C. R.	....
1,004,091	48	154.1
1,007,659	48	154.1
1,009,252	48	154.1
1,021,326	48	154.1

United States patents—Continued.

Patent No.	Present official— Class.	Subclass.
New class 1, carburetors, proportioning-flow fixed air and fuel inlets, periodic fuel valve—Continued.		
1,029,606	48	154.1
1,044,314	48	154.1
1,049,318	48	154.1
1,063,866	C. R.	....
1,111,179	48	154.1
1,120,397	48	154.1
1,124,911	48	154.1
1,128,968	48	154.1
1,130,228	48	154.1
1,137,728	48	154.1
1,145,854	48	154.1
1,146,181	48	154.1
1,151,156	123	123
1,172,258	48	154.1
New class 1.1, mechanically-operated fuel valve, single air inlet:		
433,806	C. R. 2	....
433,807	C. R.	....
437,507	123	35
456,284	C. R. 2	....
482,202	C. R. 2	....
525,857	C. R. 2	....
537,370	C. R. 2	....
550,451	C. R. 2	....
573,762	123	122
574,183	123	121
585,115	C. R.	....
596,809	123	122
	123	123
527,887	C. R.	....
658,594	123	121
659,095	123	123
679,053	123	121
690,481	C. R. 2	....
728,873	123	35
740,571	C. R.	....
751,292	48	150.2
788,748	123	123
792,894	123	121
806,822	123	119
846,434	C. R. 2	....
857,111	48	168
858,046	123	133
885,598	123	123
924,483	C. R. 2	....
951,353	123	35
New class 1.2, single air inlet with automatic valve, fuel inlet in seat:		
417,924	C. R. 2	....
418,029	123	129
523,511	C. R. 2	....
532,100	C. R. 2	....
539,710	C. R. 2	....
555,717	C. R.	....
563,541	C. R.	....
593,043	C. R. 2	....
593,911	48	155
598,986	123	34
600,147	C. R. 2	....
603,986	C. R. 2	....
627,219	C. R. 2	....
635,166	48	155.1
645,044	C. R.	....
683,110	48	168
690,112	48	154.1
700,295	123	35
719,536	48	155.1
722,357	48	154.1
729,377	123	123
731,218	48	154.1
755,093	123	141
782,471	123	123
806,139	C. R. 2	....
New class 1.2, single air inlet with automatic valve, fuel inlet in seat—Continued.		
817,721	48	155
819,239	123	25
856,760	C. R. 2	....
866,490	48	154.1
868,392	123	129
874,822	C. R. 2	....
877,753	123	129
894,656	48	150.2
913,313	48	154.1
922,374	48	154.1
922,383	C. R.	....
948,977	48	154.1
955,218	123	123
970,251	123	141
	261	50
973,056	48	155.2
978,787	48	154.1
995,919	48	150.2
	48	155.2
1,046,141	48	154.1
1,048,518	48	150.3
Re. 13,580	....	....
1,067,351	48	154.1
1,086,359	48	154.1
1,095,622	48	150.1
1,101,147	48	150.1
1,156,836	48	148
New class 1.3, single air inlet automatic valve, fuel inlet beyond:		
448,386	C. R. 2	....
498,447	48	154.1
500,401	48	154.1
509,828	48	154.1
515,050	48	154.1
552,263	123	123
567,253	48	154.1
578,683	48	154.1
588,466	123	122
593,911	C. R.	....
609,557	48	154.1
616,974	48	150.2
632,917	C. R. 2	....
633,800	48	154.1
638,529	48	148
665,496	48	148
671,743	123	132
619,776	C. R. 2	....
676,285	123	122
680,572	48	154.1
680,961	C. R.	....
681,287	C. R. 2	....
694,708	48	154.1
709,126	123	123
709,428	123	136
710,841	C. R.	....
746,701	C. R. 2	....
756,908	48	151.1
799,791	48	155.2
806,125	C. R.	....
835,564	48	155.2
837,984	48	168
863,516	48	154.1
882,023	48	155.2
892,501	C. R. 2	....
904,508	C. R.	....
912,998	48	154.1
912,999	48	154.1
930,443	48	154.1
938,894	48	154.1
952,547	48	150.2
963,804	48	154.1
964,409	C. R.	....
964,831	48	154.1
988,659	48	154.1
1,022,803	C. R. 2	....

United States patents—Continued.

Patent No.	Present official— Class.	Present official— Subclass.
New class 1.3, single air inlet automatic valve, fuel inlet beyond—Continued.		
1,061,582	48	154.1
1,063,630	48	154.1
1,066,080	48	154.1
1,111,897	C. R.	....
1,137,727	48	154.1
New class 1.4, double air inlet, primary and secondary:		
610,460	C. R. 2	....
679,387	48	154.1
715,398	48	154.1
717,000	48	154.1
726,191	48	155
726,671	C. R.	....
741,224	48	154.1
800,777	48	148
888,263	48	154.1
896,388	48	154.1
903,206	48	154.1
938,894	48	155.2
939,856	48	154.1
951,002	48	154.1
1,178,530	48	148
1,181,514	48	155.1
New class 2, carburetors, proportioning flow, metering fuel pump, air motor driven:		
249,363	48	153
791,801	48	155.1
957,976	48	155.1
1,048,083	48	154.1
1,119,479	48	152
1,137,120	48	155
1,137,238	48	155.1
1,149,323	48	152
1,150,115	48	148
1,153,077	48	152
New class 3, carburetors, proportioning flow, aspirating, single fixed fuel and air inlets:		
439,313	C. R.	....
477,295	C. R.	....
542,043	C. R.	....
550,675	C. R.	....
613,757	C. R.	....
627,857	C. R.	....
633,274	123	132
634,242	48	155.1
640,394	C. R. 2	....
640,674	C. R. 2	....
644,566	48	155.1
650,736	123	141
658,267	123	132
670,803	C. R. 2	....
671,714	123	123
682,596	48	155.1
682,606	C. R. 2	....
685,993	48	149
690,610	C. R.	....
690,989	48	155.1
694,110	48	148
696,146	C. R.	....
702,469	48	155.1
703,769	C. R.	....
705,995	48	154.1
706,494	C. R.	....
711,005	48	155.1
721,238	48	155
724,648	48	155.1
729,467	48	155.1
730,084	C. R.	....
737,848	48	155.1
772,530	C. R.	....
781,936	48	148
790,379	123	132
New class 3, carburetors, proportioning flow, aspirating, single fixed fuel and air inlets—Continued.		
804,589	261	15
812,371	C. R. 2	....
816,109	C. R. 2	....
822,172	C. R.	....
846,903	48	155.1
849,048	123	136
854,246	48	155.1
855,179	48	155.1
867,604	48	155
872,336	C. R.	....
891,064	C. R. 2	....
915,647	48	155.1
917,283	123	25
936,337	48	155.1
939,481	48	155
975,796	C. R.	....
1,006,033	48	155.2
1,008,155	48	144
1,013,759	48	150.1
1,026,491	48	155.1
1,081,900	48	155
1,084,151	48	150.1
1,103,451	123	122
1,105,017	123	122
1,109,025	C. R.	....
1,110,438	123	127
1,118,459	48	155.1
1,160,662	48	155.1
1,166,967	48	150.1
1,171,200	48	150.1
1,178,972	123	122
1,179,664	48	144
New class 3.1, fuel inlet at air throat:		
350,769	C. R.	....
657,739	123	132
657,740	48	155
693,773	48	155.1
733,695	261	12
765,814	C. R. 2	....
789,537	48	155.1
858,586	123	131
887,370	123	132
890,273	48	155.1
897,259	123	119
906,980	123	132
928,939	C. R.	....
954,905	48	148
984,032	C. R.	....
1,014,988	123	180
1,026,425	C. R. 2	....
1,033,505	123	7
1,038,699	C. R.	....
1,052,897	48	155.2
1,054,728	C. R. 2	....
1,063,666	123	7
1,068,195	C. R. 2	....
1,081,258	C. R.	....
1,101,913	123	122
1,102,025	123	73
1,107,636	C. R. 2	....
1,117,641	C. R.	....
1,117,642	C. R.	....
1,130,981	48	155.1
1,148,166	123	25
1,153,364	123	99
1,190,714	48	219
New class 3.2, air guides or baffles:		
660,482	C. R.	....
699,504	48	155.1
737,463	48	155.1
791,501	C. R.	....
797,972	48	155.1

United States patents—Continued.

Patent No.	Present official— Class.	Subclass.
New class 3.2, air guides or baffles—Continued.		
817,641	48	155.1
817,941	123	132
825,754	48	155.1
844,900	123	133
	261	68
862,083	48	155.1
886,283	48	168
908,112	C. R.	....
931,389	C. R.	....
1,072,376	48	155.1
1,109,192	C. R.	....
1,134,021	48	155.1
1,141,570	48	148
New class 3.3, rotating fuel spreader, air driven:		
868,707	123	141
	261	51
1,092,953	48	155.1
1,178,127	48	155.1
New class 3.4, variable jet and throat relation:		
656,197	48	155.2
1,086,226	48	155.1
1,149,908	48	154.1
New class 3.5, variable float chamber pressure:		
686,101	C. R.	....
741,962	48	155.2
954,488	48	155.1
960,601	48	155.1
961,152	C. R.	....
992,260	48	155.2
998,457	48	155.1
1,002,646	48	155.1
1,064,627	48	155.1
1,064,628	48	155.1
1,074,625	48	155.1
1,108,727	48	155.1
1,166,734	48	150.1
New class 4, carburetors, proportioning flow aspirating, single fuel, multiple air inlets, both fixed:		
504,723	C. R.	....
549,939	C. R.	....
557,496	C. R.	....
605,815	C. R.	....
664,200	C. R.	....
699,309	48	155.1
726,986	48	150.2
754,001	123	101
72,979	48	155.1
775,103	123	98
84[illegible],170	48	155.2
871,134	48	150.2
878,770	48	155.1
991,029	C. R. 2	....
994,658	123	122
995,976	48	155.2
1,003,351	48	150.1
1,006,088	48	155.1
1,019,209	48	155.1
1,031,147	48	155
1,042,079	48	155
1,072,875	48	148
1,116,986	48	155.1
1,134,365	48	155.1
1,159,167	48	150.3
1,169,483	48	155
1,174,529	48	155.1
New class 4.1, mixed flow:		
681,382	48	155.1
	123	132
684,662	48	150.1
686,092	C. R.	....
719,496	48	155.1
New class 4.1, mixed flow—Continued.		
801,539	123	132
808,920	123	132
1,065,912	48	150.3
1,121,630	48	155.1
1,130,490	48	150.3
1,149,035	48	155.1
1,183,293	48	150.1
New class 5.1, main fuel inlet, with supplementary high-speed jet:		
1,079,634	48	150.3
New class 5.2, main fuel inlet, with supplementary idling jet:		
995,074	48	150.2
1,183,294	48	150.3
New class 5.3, fuel standpipes:		
1,093,343	48	150.3
1,148,378	48	150.3
New class 6, carburetors, proportioning flow, aspirating, multiple fuel and multiple air inlets, both fixed:		
811,618	48	150.1
861,378	C. R. 2	....
1,013,983	48	148
1,097,165	48	155.1
1,102,722	48	150.1
1,125,368	48	150.3
New class 6.1, double carburetor, progressive by throttle:		
898,494	48	150.3
898,495	48	150.3
907,757	48	150.3
1,002,699	48	150.3
1,011,694	48	150.3
1,069,502	C. R.	....
1,096,482	48	155.1
1,122,571	48	150.3
New class 6.2, multiple carburetor, progressive by throttle:		
759,624	48	150.3
832,184	48	150.3
879,380	48	150.3
910,018	48	150.3
948,612	48	150.3
1,018,262	48	150.3
1,021,547	48	150.3
1,144,206	48	150.3
1,158,589	48	150.3
1,162,041	48	150.3
982,428	48	150.3
New class 6.3, double carburetor, progressive by vacuum:		
851,759	48	150.3
872,138	123	98
1,176,627	48	150.3
1,176,651	48	150.3
New class 6.4, multiple carburetor, progressive by vacuum:		
664,134	48	150.3
871,320	48	150.3
1,049,705	48	150.3
1,072,733	48	150.3
1,113,221	48	150.3
	48	155.1
1,146,150	48	150.3
1,180,976	48	150.3
1,185,016	48	150.3
New class 6.5, mixed flow:		
907,958	48	150.1
998,123	48	150.3

United States patents—Continued.

Patent No.	Present official— Class.	Present official— Subclass.
New class 6.5, mixed flow—Continued.		
1,002,700	48	150.3
1,013,708	48	155.1
1,051,041	48	150.3
1,063,148	48	150.3
1,089,372	48	150.3
1,090,047	48	150.3
1,096,626	48	150.3
Re. 14,045	48	155.1
1,099,277	48	150.1
1,109,974	48	150.3
1,112,374	48	150.3
1,116,023	48	150.3
	48	155.1
1,143,986	48	150.3
1,144,206	C. R.	....
1,153,436	48	150.1
1,170,348	48	150.3
1,170,416	48	150.3
1,170,417	48	150.3
1,175,536	48	150.3
1,176,267	48	150.2
1,177,624	48	150.3
1,183,019	48	150.3
1,183,864	48	168
1,183,673	48	150.3
New class 6.6, fuel standpipe:		
927,211	48	150.3
New class 7, carburetors, proportioning flow, aspirating, single fixed inlet and single air inlet with regulating valve:		
864,111	48	155.1
865,539	48	155.2
876,800	48	155.1
911,692	48	155.2
935,833	48	155.1
936,118	48	155.1
967,407	48	155.1
1,037,833	48	155
1,062,688	48	155.2
1,101,736	48	155.1
New class 7.1, fuel inlet between throttle-controlled air valve and throttle:		
771,492	48	150.1
789,749	48	155.1
794,927	48	155.1
810,435	C. R.	....
823,485	48	150.2
853,428	48	155.1
856,638	123	131
	48	155
861,438	48	155.2
863,739	48	155.1
867,859	48	150.2
893,685	48	155.1
896,559	123	132
932,465	48	150.3
973,602	48	150.2
976,813	48	155.1
977,831	48	155.1
1,006,387	48	150.3
1,043,077	48	155
1,044,754	48	155.1
1,054,084	48	150.1
1,062,333	48	150.1
1,077,881	123	25
1,077,910	48	150.1
1,095,101	48	155.1
1,105,003	48	144
1,118,917	48	155.1
1,124,724	48	150.1
1,135,729	48	155.1
1,139,851	48	155
1,145,990	48	150.1
1,150,202	48	150.1
New class 7.1, fuel inlet between throttle-controlled air valve and throttle—Continued.		
1,150,224	48	150.1
1,151,159	48	155.1
1,151,286	48	155.1
1,163,581	48	155.1
New class 7.2, fuel inlet at or before air valve, which acts as a throttle:		
627,372	261	51
804,025	48	155.1
815,712	48	155.1
816,846	48	155.1
832,183	48	150.3
868,251	48	155.2
1,014,188	48	155.1
1,037,834	48	155.1
1,038,804	48	155
1,045,613	48	155
1,067,449	48	155.1
1,080,118	48	150.3
1,088,974	48	155.1
1,108,181	48	150.1
1,116,581	48	155.1
1,117,233	48	150.2
1,131,312	48	155.1
1,143,227	48	155.1
1,144,549	123	106
1,161,437	48	155.1
1,165,224	48	155.1
1,171,074	48	150.3
1,172,388	48	155.2
New class 7.3, fuel inlet between automatic air valve and throttle:		
622,891	C. R.	....
657,738	123	122
666,623	48	155
673,901	123	122
688,349	123	119
759,396	48	155.1
774,079	48	155.2
785,622	48	155.2
792,628	48	155.2
794,502	48	155.1
796,723	48	155.2
806,434	123	119
820,583	48	155.2
822,681	48	155.2
829,345	48	155.1
831,547	48	155.2
869,675	48	155.2
886,760	48	155.2
896,559	48	155.2
911,106	48	155.2
921,410	48	155.2
929,327	48	155.2
947,712	48	155.1
962,140	48	155
966,381	48	154.1
983,307	C. R.	....
986,700	48	150.2
993,097	48	155.1
996,897	48	155.2
1,018,126	48	155.2
1,027,768	48	154.1
1,038,699	48	155.2
1,039,229	123	180
1,041,099	48	155.2
1,080,166	48	155.2
1,085,239	48	150.1
1,106,258	48	155.1
1,124,918	48	155.2
1,116,673	C. R.	....
1,129,864	48	155.2
1,132,580	48	150.1

United States patents—Continued.

Patent No.	Present official—	
	Class.	Subclass.
New class 7.3, fuel inlet between automatic air valve and throttle—Continued.		
1,133,845	123	122
1,141,796	48	168
1,160,837	48	150.2
1,178,866	48	154.1
1,190,540	48	154
New class 7.4, fuel inlet swept by air entering through air valve:		
783,902	48 / 48	154.1 / 155.2
791,447	48	155.2
799,232	48	148
800,647	48	155.2
855,574	48	155.2
859,719	48	155.1
875,716	48	155.2
878,411	48	155.2
904,659	48	154.1
910,379	48	155.2
916,103	48	155.2
924,200	48	155.2
925,973	48	155.2
926,533	48	155.2
928,828	48	155.1
943,197	48	155.2
950,278	48	155.1
960,697	48	155.1
963,187	48	155.1
976,344	48	155.1
973,877	48	155.2
995,919	C. R.	....
997,169	48	155.2
1,000,398	48	154.1
1,005,300	48	155.2
1,020,931	48	155.1
1,023,470	48	155.1
1,033,508	123	7
1,042,982	48	155.2
1,052,051	48	155.1
1,064,028	C. R.	....
1,068,181	48	155.1
1,093,901	48	155.2
1,095,384	48	150.1
1,110,041	48	155.2
1,124,949	48	155.1
1,131,584	48	155.2
1,140,000	C. R.	....
1,148,247	48	148
1,157,541	48	155.1
1,180,152	48	150.2
1,180,389	48	155.2
1,180,939	48	155.1
1,184,873	48 / 48	155 / 155.1
New class 7.5, variable float chamber pressure:		
877,890	48	150.1
993,096	48	154.1
1,103,802	48	155.1
1,167,457	48	148
New class 8, carburetors, proportioning flow, aspirating, single fixed fuel inlet, multiple air inlets, valved for regulating:		
751,434	123	127
828,226	48	155.1
844,890	123	124
911,349	48	155.1
920,642	48	155.2
929,260	48	155.2
944,048	48	155.2
970,916	48	155.2
983,836	48	155.1
985,670	48	155.2
997,232	123	124
998,355	123	98
New class 8, carburetors, proportioning flow, aspirating, single fixed fuel inlet, multiple air inlets, valved for regulating—Continued.		
1,000,054	48	155.2
1,001,969	48	155.2
1,005,300	C.R.	....
1,019,128	48	155.2
1,020,059	48	155.2
1,029,685	123	98
1,062,688	C. R.	....
1,073,473	48	155.2
1,082,466	48	155.1
1,089,105	48	150.3
1,096,819	123	73
1,099,086	48	148
1,104,453	48	168
1,104,762	48	150.1
1,105,687	123	119
1,119,757	48	155.2
1,122,703	48	148
1,123,027	48	155.1
1,123,955	48	155.1
1,127,992	48	155.2
1,128,717	123	52
1,129,103	48	155.1
1,134,942	48	150.3
1,135,046	48	155.1
1,137,307	48	155.1
1,150,782	48	155 1
1,151,989	48	150.2
1,173,378	48	155.1
1,173,395	48	155.1
New class 8.1, two air inlets, fixed primary, throttle controlled secondary, regulating air valve:		
730,649	48	155.1
733,625	48	148
767,716	48	155.1
775,553	48	155.1
794,851	48	155.1
825,531	C. R. 2	....
832,532	C. R.	....
840,204	48	155.2
842,052	48	155.1
851,285	48	155.1
886,527	48	155.1
889,558	48	155.1
908,764	48	155.1
924,673	48	155.1
954,530	48	155.1
959,066	C. R.	....
965,703	123	100
1,011,565	48	155.1
1,060,053	123	34
1,064,514	123	100
1,081,203	48	155.1
1,097,401	48	155.1
1,119,181	48	155.1
1,123,027	48	155.1
1,148,333	48	155.1
1,148,898	48	155.1
1,149,597	123	108
1,154,630	48	150.1
1,184,888	48	155.1
1,184,889	48	155.1
1,185,273	48	155.2
Class 8.2, two air inlets, fixed primary, automatic secondary regulating air valve:		
649,324	48	155.1
664,841	48	155.2
713,146	48	155.2
734,421	123	123
741,810	48	149
759,001	123 / 48	122 / 155.1
785,558	48	155.2

United States patents—Continued.

Patent No.	Present official— Class.	Present official— Subclass.
Class 8.2, two air inlets, fixed primary, automatic secondary regulating air valve—Continued.		
792,878	48	150.2
796,712	C. R.	....
802,216	48	155.2
810,792	48	155.2
823,742	C. R.	....
831,832	123	124
	48	155.2
835,880	48	155.2
850,339	48	155.2
856,958	48	155.2
857,275	48	155.2
860,848	48	155.2
864,687	48	155.2
882,170	123	108
886,526	48	155.1
888,487	48	155.2
888,965	48	155.2
898,361	48	155.1
899,109	48	155.2
900,098	48	155.1
900,731	48	155.2
907,279	48	155.1
912,083	48	155.2
913,354	48	155.1
926,598	48	155.2
927,529	48	155.2
928,042	48	155.2
932,360	48	155.2
932,860	48	155.2
942,977	48	155.2
943,242	48	155.2
945,167	48	155.1
968,597	48	155.2
974,076	48	155
976,558	48	155.2
976,692	48	155.1
977,377	48	155.2
979,908	48	150.2
981,156	48	155.2
984,276	48	155.2
997,233	48	155.2
997,929	48	150.2
1,003,994	48	155.2
1,006,663	48	155.2
1,013,082	48	155.2
1,016,251	48	155.1
1,017,750	C. R. 2	....
1,018,776	48	155.2
1,035,937	48	155.2
1,038,262	48	155.2
1,041,480	48	155.2
1,043,342	48	148
1,043,692	48	155.2
1,044,569	48	155.2
1,044,576	48	155.2
1,044,594	48	155.2
1,046,344	48	155.2
1,053,145	48	155.2
1,059,368	48	155.2
1,061,626	48	148
1,062,273	48	155.2
1,064,445	48	155.2
1,065,640	48	148
1,065,948	48	148
1,067,502	48	155.2
Re. 13,784	....	....
1,067,906	123	122
1,069,399	48	150.1
1,069,671	48	155.2
1,071,858	48	155.2
1,073,695	48	155.2
1,076,827	48	155.2
1,078,169	48	155.2
1,078,766	48	155.2
1,079,338	C. R.	....
1,080,645	48	155.2
1,086,287	48	155.2
1,089,423	48	155.2
1,090,556	48	155.2
1,092,282	48	155.2
1,093,627	48	155.2
1,095,212	48	155.2
1,095,326	48	155.2
1,099,714	48	155.2
1,104,975	48	155.2
1,105,142	123	108
1,106,115	123	136
1,106,145	48	155.2
1,106,881	123	122
1,107,693	48	155.2
1,109,356	48	155.2
1,112,257	123	119
1,115,543	48	155.2
1,118,919	48	155.1
1,120,303	48	155.2
1,130,915	C. R. 2	....
1,131,371	C. R.	....
1,133,452	48	148
1,135,315	48	155.1
1,136,368	C. R.	....
1,137,057	123	122
1,137,135	48	150
	48	150.1
1,139,364	123	73
1,140,064	48	148
1,141,086	48	155.2
1,142,793	48	150.1
1,143,092	48	150.2
1,143,961	48	150.1
1,145,138	48	155.2
1,148,461	48	155.2
1,150,619	48	148
1,155,282	48	155
1,156,149	48	155.2
1,158,435	48	150.2
1,160,239	48	150.1
1,162,576	48	155.1
1,166,595	48	155.2
1,167,320	48	155.2
1,171,145	123	122
1,172,263	48	150.1
1,172,432	48	155.2
1,176,729	48	155.2
1,180,379	48	155.2
1,184,695	48	150.2
New class 8.3, two air inlets, both with regulating valves, one automatic, the other throttle-controlled:		
1,060,545	48	154.1
New class 8.4, two air inlets, both with automatic regulating valves:		
667,910	48	155.2
762,707	48	148
790,173	48	155.2
806,830	48	155.2
890,494	48	155.2
960,080	48	155.2
989,697	48	155.2
1,136,675	48	148
1,141,258	48	150.1
	48	155
1,159,933	48	148
1,183,137	48	155.2
New class 8.5, two air inlets, both with throttle-controlled regulating valves:		
714,597	48	155.1
776,406	48	155.1

United States patents—Continued.

Patent No.	Present official—	
	Class.	Subclass.
New class 8.5, two air inlets, both with throttle-controlled regulating valves—Continued.		
846,471	C. R.	....
856,638	....	....
871,730	48	154.1
905,012	48	155
964,657	48	148
976,322	48	155.1
985,431	48	155.1
988,800	48	155.1
993,516	261	38
1,014,328	123	100
1,072,565	48	155.1
New class 8.6, mixed flow:		
423,214	48	154.1
595,552	123	132
802,038	48	155.1
952,326	48	154.1
1,061,835	48	150.3
1,095,510	48	155.1
New class 9, carburetors, proportioning flow, aspirating, multiple fixed fuel inlets, single air inlet with regulating valve:		
1,177,538	48	150.1
New class 9.1, fuel inlets act progressively with opening of single automatic air-inlet regulating valve:		
1,006,130	48	150.3
1,011,960	48	150.3
1,074,574	48	150.3
1,074,575	48	150.3
1,119,076	48	154
	48	150.3
1,130,474	48	150.3
1,130,950	48	150.3
1,173,246	48	150.3
1,185,492	48	150.3
New class 9.2, fuel inlets act progressively with opening of single throttle controlled air-inlet regulating valve, or air valve acting as throttle:		
858,437	48	150.3
881,279	48	155.1
881,800	48	150.3
989,515	48	150.3
1,010,051	48	150.3
1,073,179	48	150.3
1,089,524	48	150.3
1,094,674	48	150.3
1,142,763	48	155.1
1,159,851	48	150.3
1,162,308	48	150.3
1,183,221	48	150.1
1,183,222	48	150.3
New class 9.3, fuel standpipes:		
1,130,700	48	150.3
1,147,237	48	150.3
New class 9.4, two fuel inlets, one main and one idling:		
825,499	48	155.1
1,016,108	48	150.3
1,147,940	48	150.3
New class 9.5, tilting fuel chamber, radially disposed fuel inlets:		
989,307	48	150.3
1,065,977	48	150.3
1,074,577	48	150.3
1,100,679	48	150.3
1,101,869	48	150.3
1,184,267	48	150.3
New class 10, carburetors, proportioning flow, aspirating, multiple fixed fuel inlets with air inlets, valved for regulation:		
979,700	48	150.3
1,014,551	48	150.3
1,099,547	48	150.3
1,163,393	48	150.1
	48	150
1,166,112	48	150.3
New class 10.1, main fuel inlet, with supplementary high-speed jet:		
928,121	48	150.3
958,476	48	150.3
978,558	48	150.3
993,770	48	150.3
1,022,708	48	150.3
1,041,481	48	150.3
1,046,434	48	150.3
1,078,349	48	150.3
1,089,089	48	150.3
1,090,208	48	150.3
1,090,209	48	155.1
1,099,298	48	150.3
1,107,849	48	155.2
1,119,078	48	155.2
1,120,763	48	155.1
1,128,773	48	150.3
1,134,531	48	155.2
1,134,532	48	155.2
1,159,423	48	155.2
1,163,223	48	150.3
1,177,318	48	155.2
1,178,473	48	154.1
1,180,518	48	150.3
New class 10.2, main fuel inlet, with supplementary idling jet:		
1,055,352	48	155.2
1,104,560	48	150.3
1,153,487	48	150.3
1,166,308	48	150.3
1,181,128	48	150.3
New class 10.3, multiple carburetor, progressive, by throttle, with individual automatic inlet, regulating valves:		
871,741	48	150.3
881,416	48	150.3
891,219	48	150.3
900,604	48	150.3
1,001,950	88	150.3
1,088,091	48	150.3
1,113,551	48	150.3
1,152,031	48	150.3
1,172,701	48	150.3
1,179,278	48	150.1
1,180,483	48	150.3
1,183,061	48	150.3
New class 10.4, multiple carburetor, progressive, by vacuum, with individual automatic air inlet regulating valves:		
1,040,414	48	150.3
1,108,245	48	150.3
New class 10.5, fuel standpipe:		
961,481	48	150.3
1,010,116	48	150.3
1,133,527	48	148
New class 10.6, mixed flow:		
973,755	48	155.2
1,040,619	48	150.3

United States patents—Continued.

Patent No.	Present official—	
	Class.	Subclass.
New class 10.6, mixed flow—Continued.		
1,103,903	48	150.3
1,123,469	48	150.3
1,168,513	48	158.3
1,169,616	48	150.3
New class 11.1, single fuel inlet valve, throttle controlled:		
583,508	123	123
727,972	48	155.1
746,449	48	155.1
771,985	48	155.1
873,392	48	155.1
917,264	48	168
984,109	48	154.1
1,065,042	48	155.1
1,097,039	C. R.	....
1,120,183	48	150.3
1,124,697	48	150.3
1,126,690	48	154.1
1,153,999	48	155.1
New class 11,2, single fuel inlet, independently controlled by air flow or vacuum:		
725,741	48	155
746,119	48	148
946,632	48	154.1
973,262	48	150.3
1,065,508	48	155.1
1,085,194	48	154.1
1,092,079	48	154.1
1,111,763	48	155.1
1,138,829	48	150.1
1,155,407	48	150.1
New class 11.3, mixed flow:		
771,096	48	155.1
New class 12, carburetors, proportioning flow, aspirating, single fuel and air inlets, both with regulating valves:		
548,922	C. R. 2	....
839,707	C. R.	....
876,210	48	154.1
973,855	48	155.1
1,007,659	C. R.	....
1,032,547	48	154.1
1,045,251	48	155
1,061,995	48	155.1
1,123,876	48	144
1,155,457	C. R.	....
1,169,574	48	154.1
New class, 12.1, valved fuel inlet beyond air-inlet valve, acting as throttle, fuel valve controlled by air valve:		
623,568	123	132
624,594	C. R. 2	....
654,894	48	155
674,034	48	150.3
677,283	C. R.	....
696,060	123	131
711,902	123	132
727,565	123	102
745,063	48	155.1
751,913	261	44
775,614	48	168
779,490	123	123
791,810	48	155.1
795,273	123	129
807,144	48	155
807,479	C. R.	....
816,477	48	154.1
818,853	261	41
836,764	48	155
879,884	C. R. 2	....
880,032	123	108
894,225	48	150
New class 12.1, valved fuel inlet beyond air-inlet valve, acting as throttle, fuel valve controlled by air valve—Continued.		
909,490	48	154.1
911,143	48	155.1
920,979	48	150.3
926,039	48	155.1
936,064	48	154.1
958,128	48	155.1
968,215	48	155
976,911	48	154.1
977,813	48	150.2
980,668	48	155.1
985,999	48	155.1
988,638	48	155.1
999,686	48	154.1
1,000,518	48	155.1
1,003,019	123	131
1,013,955	C. R.	....
1,014,945	48	148
1,028,723	48	155.1
1,084,693	C. R.	....
1,086,594	48	155.1
1,099,995	C. R.	....
1,107,713	48	155.1
1,107,698	48	155.1
1,121,651	48	150.1
1,145,824	48	150.3
1,157,363	48	155.1
1,171,235	48	155.1
1,172,595	48	154.1
1,183,125	48	155.1
1,184,541	48	155.1
1,190,124	48	156
New class 12.2, valved fuel inlet between air-inlet valve and throttle, both fuel and air valves controlled by the throttle:		
780,949	48	155.1
795,357	48	155.1
805,979	123	132
813,683	48	155.1
821,061	48	155.1
827,094	48	155
848,425	48	154.1
865,522	48	155.1
883,740	48	155.1
907,881	48	155.1
910,326	48	155.1
922,145	C. R.	....
937,536	48	155.1
956,882	48	155.2
958,897	48	155.1
973,937	48	155
983,247	48	155.1
983,541	48	155.1
993,210	48	154.1
1,000,451	48	155.1
1,006,491	48	155.1
1,007,729	48	155.1
1,011,696	48	150.3
1,012,781	48	155.1
1,018,164	C. R.	....
1,021,198	48	155.1
1,027,459	48	155.1
1,033,886	48	155
1,042,528	48	156
1,042,606	48	156
1,052,397	48	155.1
1,065,067	48	155.1
1,072,492	48	155.1
1,076,268	123	123
1,080,815	48	150.3
1,085,008	48	155.1
1,105,200	48	155.1

United States patents—Continued.

Patent No.	Present official— Class.	Subclass.
New class 12.2, valved fuel inlet between air-inlet valve and throttle, both fuel and air valves controlled by the throttle—Continued.		
1,120,845	48	155.1
1,125,069	48	150.3
1,129,129	48	155.1
1,135,544	48	155.1
1,143,511	48	155.1
1,153,891	48	155.1
1,155,094	123	123
1,176,516	48	148
1,178,296	48	155.1
1,183,587	48	150.3
1,185,574	48	155.1
New class 12.3, valved fuel inlet at or in front of air valve, acting as throttle, fuel valve controlled by air valve:		
626,120	123	103
626,121	C. R. 2	
635,218	C. R. 2	
648,001	C. R. 2	?
746,833	48	154.1
855,582	C. R.	
862,574	123	100
873,392	C. R.	
887,422	123	129
904,855	C. R.	
930,742	48	155.1
977,044	48	150.3
1,038,921	48	155.1
1,053,136	48	155.1
1,140,232	48	155.1
1,151,578	48	155.1
1,152,173	48	150.3
1,184,923	48	150.3
1,190,573	48	150.3
New class 12.4, valved fuel inlet between automatic air-inlet valve and throttle, fuel valve controlled by throttle:		
747,264	C. R.	
755,074 / Re. 12,611	48	150.3
792,670	48	150
823,608	48	155.1
835,773	C. R. 2	
920,231	48	155.1
947,633	123	35
961,590	48	155.2
1,010,714	48	155.2
1,018,164	48	155.2
1,019,160	48	155.2
1,042,982 / Re. 13,837	48	155.2
1,044,245	48	155.2
1,066,608	48	155.2
1,103,178	48	155.1
1,112,641	48	150.1
	48	154.1
1,126,127	48	155.1
1,132,314	48	155.1
1,155,457	48	150.3
1,176,816	48	148
1,181,356	48	154.1
1,190,125	48	156
New class 12.5, valve fuel inlet between automatic air-inlet valve and throttle, fuel valve controlled by automatic air valve:		
687,840	261	50
735,483	123	128
770,559	48	156
807,479	48	154.1
818,853	48	150.3
826,531	48	154.1
	48	155.1
New class 12.5, valve fuel inlet between automatic air-inlet valve and throttle, fuel valve controlled by automatic air valve—Continued.		
839,707	48	154.1
876,287	48	155.2
892,155	48	154.1
895,709	48	150.3
901,345	48	150.3
906,671	261	57
926,848	48	154.1
941,406	48	154.1
941,424	48	150.3
954,785	48	150.3
971,038	48	154.1
978,947	48	154.1
982,297	48	150.3
984,874	48	154.1
988,502	48	154.1
994,195	48	154.1
995,623	48	154.1
996,981	48	154.1
997,417	48	154.1
998,993	48	154.1
1,001,847	48	154.1
1,003,101	48	154.3
1,006,411	48	154.1
1,010,003	48	154.1
1,014,319	48	154.1
1,016,169	48	154.1
1,020,270	48	154.1
1,032,307	48	154.1
1,033,130	48	154.1
1,040,528	48	154.1
1,042,017	48	154.1
1,046,111	48	154.1
1,049,417	48	154.1
1,049,887	48	154.1
1,050,059	48	154.1
1,059,501	48	154.1
1,064,867	48	154.1
1,078,413	48	154.1
1,078,592	48	154.1
1,084,693	48	154.1
1,088,231	48	154.1
1,097,787	48	154.1
1,103,864	48	155.1
	48	154.1
1,104,494	48	154.1
1,115,951	48	154
	48	154.2
1,116,673	48	155.1
1,119,821	48	155.1
1,120,128	48	154.1
	48	154
1,123,048	48	154.1
1,125,525	48	154.1
1,126,249	48	154.1
1,130,350	48	150.3
1,133,754	48	155.1
1,135,211	48	150.3
1,138,204	48	154.1
1,139,914	48	154.1
1,140,525	C. R.	
1,141,065	48	154.1
1,143,779	48	150.2
1,145,172	48	154.1
1,145,871	48	154.1
1,147,644	48	150.2
1,149,291	48	150.3
1,159,005	48	154.1
1,159,029	48	154.1
1,159,049	48	154.1
1,161,374	48	154.1
1,162,680	48	150.3
1,166,173	48	148
1,167,426	48	154.2
1,168,782	48	154.1

United States patents—Continued.

Patent No.	Present official—	
	Class.	Subclass.
New class 12.5, valve fuel inlet between automatic air-inlet valve and throttle, fuel valve controlled by automatic air valve—Continued.		
1,168,783	48	154.1
1,171,679	48	154.1
1,171,716	48	154.1
1,172,397	48	148
1,176,600	48	150.1
1,178,832	48	150.3
1,179,568	48	154.1
1,179,913	48	154.1
1,182,714	48	148
1,183,183	48	150.3
1,190,715	48	155.1
New class 12.6, valved fuel inlet between air-inlet valve and throttle, fuel valve controlled independently by vacuum or air flow:		
838,085	123	124
	48	155.2
918,607	48	154.1
1,048,954	48	154.1
1,087,218	48	154.1
1,091,426	48	155.1
1,126,159	48	154.1
1,133,904	48	150.3
1,137,727	C. R.	....
1,148,247	C. R.	....
New class 12.7, variable float chamber pressure:		
1,010,066	48	150.3
1,010,184	48	154.1
1,025,816	48	154.1
1,029,897	48	154.1
New class 13, carburetors, proportioning flow, aspirating, single fuel and multiple air inlets, both with regulating valves:		
813,653	48	155.2
817,903	48	155.1
849,538	C. R.	....
876,579	123	123
889,487	48	155.1
1,051,440	48	154.1
1,078,582	48	150.3
1,087,218	C. R.	....
1,118,805	48	150.2
1,132,934	48	154.1
1,154,530	123	123
1,158,324	48	154.1
1,178,064	48	154.1
1,191,156	48	156
New class 13.1, valved fuel inlet, fixed primary air, fixed or valved secondary air inlet, throttle control of fuel inlet valve and of secondary air valve:		
886,265	48	155.2
892,499	48	150.3
950,423	48	154.1
955,292	48	155.1
976,258	48	150.3
1,029,796	48	155
1,036,301	48	155
1,065,462	48	155.1
1,088,664	48	155.1
1,116,192	C. R.	....
1,125,339	48	155.1
1,125,340	48	155
1,140,721	48	155.1
1,148,485	48	150.3
1,156,084	48	150.3
1,163,749	48	155
1,191,522	48	156
1,192,213	48	155.1
New class 13.2, valved fuel inlet, valved primary and secondary air inlets, throttle control of both air inlets and fuel inlet valve:		
860,908	48	155.2
1,134,366	48	148
1,162,111	48	155.1
1,179,663	48	155.1
New class 13.3, valved fuel inlet, fixed primary and throttle-controlled secondary air inlets, fuel valve controlled by the vacuum or air flow independently:		
1,079,947	48	154.1
1,081,222	48	154.1
1,125,238	48	155.1
1,131,157	C. R.	....
New class 13.4, valved fuel inlet, fixed primary and automatic valved secondary air inlets, fuel valve controlled by the throttle:		
744,257	48	155.2
870,052	48	155.2
971,689	48	155.2
971,862	48	154.1
1,042,004	48	155.2
1,052,917	48	155.2
1,057,506	48	155.1
1,096,569	48	155.2
1,106,226	48	155.2
1,106,802	123	132
1,113,533	48	155.2
1,122,572	48	155.2
1,126,218	48	155.2
1,140,071	48	155.1
1,140,722	48	155.1
1,152,134	48	150.1
1,171,401	48	155.2
1,173,762	48	155.1
New class 13.5, valved fuel inlet, fixed primary and automatic valved secondary air inlets, fuel valve controlled by the automatic secondary air valve:		
844,894	48	155.2
855,170	48	155.2
876,287	C. R.	....
886,545	48	154.1
920,731	C. R.	....
962,649	48	154
976,237	C. R.	....
979,555	48	154.1
981,853	48	154.1
994,191	48	154.1
1,010,185	48	154.1
1,014,682	48	154.1
1,022,702	48	150.3
1,030,343	48	154.1
1,038,050	48	155.2
1,042,017	C. R.	....
1,046,111	C. R.	....
1,067,623	48	154.1
1,069,389	48	154.1
1,069,817	48	150.3
1,071,003	48	154.1
1,077,256	48	154.1
1,078,413	C. R.	....
1,078,590	48	154.1
1,078,591	48	154.1
1,080,696	48	154.1
1,095,402	48	154.1
1,106,226	C. R.	....
1,111,224	48	150.1
1,114,222	48	154.1
1,118,126	48	148
1,120,573	48	154

United States patents—Continued.

Patent No.	Present official—	
	Class.	Subclass.
New class 13.5, valved fuel inlet, fixed primary and automatic valved secondary air inlets, fuel valve controlled by the automatic secondary air valve—Continued.		
1,120,57[illegible]	48	154.1
1,130,5[illegible]	48	148
1,135,6[illegible]	48	154.1
1,140,5[illegible]	48	154.1
1,155,7[illegible]	48	148
1,156,8[illegible]	48	154.1
1,158,3[illegible]	48	154.1
1,158,4[illegible]	48	148
1,165,3[illegible]	48	154.1
1,167,21[illegible]	48	150.2
1,179,70[illegible]	48	150.2
1,183,53[illegible]	48	154.1
1,184,6[illegible]	48	154.1
New class 13.6, valved fuel inlet, valved primary and secondary air, both automatic, fuel valve controlled by one of both automatic air inlet valves:		
917,125	48	154.1
1,022,3[illegible]	48	155.2
1,036,53[illegible]	48	155.1
1,084,95[illegible]	48	154.1
1,087,18[illegible]	48	154.1
1,105,13[illegible]	48	155.2
1,125,52[illegible]	C. R.	....
New class 14, carburetors, proportioning flow, aspirating, multiple fuel and air inlets, both with regulating valves:		
1,123,50[illegible]	123	123
1,163,74[illegible]	48	155.1
New class 14.1, two fuel inlets, one fixed main and one valved supplementary high-speed jet, two air inlets, one fixed primary and one valved secondary:		
1,038,040	48	150.3
1,164,661	48	150.3
1,172,031	48	150.3
1,179,286	48	155.2
1,179,381	48	150.3
New class 14.2, multiple carburetors, progressive by throttle or vacuum:		
1,046,014	48	150.3
1,120,184	48	150.3
1,120,185	48	150.3
1,157,116	48	150.1
New class 15.1, thermostatic controls:		
1,017,572	48	149
1,091,521	48	149
1,105,016	123	127
1,110,131	48	150
1,133,872	....	....
1,135,270	48	154.1
1,137,219	48	148
1,142,824	48	148
1,143,230	123	124
1,145,476	48	149
1,149,743	48	155.1
1,165,087	48	155.1
1,180,786	123	124
New class 15.2, barometric controls:		
1,049,038	48	155.1
1,098,783	48	144

REPORT NO. 11.

PART IV.

STRUCTURAL CHARACTERISTICS AND FUNCTIONAL OPERATION OF EACH OF THE NEW CLASSES AND SUBCLASSES OF PROPORTIONING-FLOW CARBURETORS.

By Charles E. Lucke.

GENERAL.

Carburetors, as devices or appliances for making a suitable explosive mixture of air with a volatile liquid fuel, were not created with any definite class idea of the mixture requirements of the engine or of the mixture-making characteristics of the various physical principles of functional operation and the mechanical limitations on the execution of each. At the time when oil refining began to produce the light petroleum distillates, now so generically classed as gasoline, in any quantity internal-combustion engines were in operation, using manufactured illuminating gas and natural gas as fuel. Something was known of these engines through the familiarity of use, and the means of making explosive mixtures of such gases and air as the working fluid for their operation were understood. Most of these engines were small; all were stationary and operated at constant speed; and practically all, if not quite so, were governed by hit-and-miss appliances, according to which the quantity of fuel and air per suction stroke is constant when any is taken at all, and no graduation of the charge per stroke with load. Under such circumstances the mixer and proportioner could be of the simplest conceivable sort—no more than two holes, one through which the gas could flow and the other for the air, with a manual adjustment for the size or area of one or both to secure the desired working proportions. Usually the gas supply came to the engine under pressure—whatever pressure existed in the mains of the city or in the natural-gas distributing pipes—so it is natural that a periodic operating valve should be added to the gas connection so gas would not flow out except during engine suction, the gas valve being opened during the suction stroke, either automatically by the suction or mechanically from the valve gear by a direct connection to the main inlet valve motion. Adjustment of proportionality of gas to air and its maintenance under such conditions of use is no more difficult than for steady, continuous flow, and two openings, the relative area of which is manually adjustable, will quite accurately fix the proportions, whether a periodic fuel stop valve be added or not. The proportions will be maintained so long as the gas pressure does not change, a condition met by the addition of a gas-pressure governor to the system.

This situation is most significant, because it explains not only the origin of one large class of early engine carburetors, but also the trend of development from this group of carburetors must necessarily have been strongly influenced by the nature of the start. This influence of the early carburetor, designed to replace the gas mixer and proportioner of early hit-and-miss gas engine to make it a corresponding gasoline engine, has been doubly strong on the rest of the art because such engines are still in use and others have appeared for which the same sort of carburetor or "gasoline mixer" is equally adapted. Such, for example, is the case with the small single cylinder two-cycle boat engine, where a constant charge per stroke is taken and the speed is normally constant and simplicity and cheapness in all parts are more important than high efficiency or light weight per horsepower.

Assuming a grade of gasoline such that the amount that air could support in combustion would immediately vaporize when mixed with it, a grade easily obtained in the early oil refining days, then feeding and proportioning such a fuel to its air involves no different problem than had already been solved for gaseous fuel. Therefore, there appeared quite early this class of carburetors, now often called "mixers," which involved at first a supply of gasoline under pressure maintained by an elevated tank, a fuel valve periodically opening with the engine suction valve to stop the fuel flow between suctions, a manually adjusted restricting valve in the gasoline line, always open for securing the desired proportions, and arranged so that the gasoline could run into the air in any way at all when it did flow. The variations in structural form that this simple arrangement can take are somewhat surprising as revealed by the cases under class 1 and its subclasses, from which practically all later schemes and modern practice in gasoline proportioning flow carburetors may be said to have been developed.

Of course, a pressure supply of such a volatile fuel involves elements of risk, both of explosion and fire, as well as trouble in operation when valve leakage between strokes becomes appreciable, which need only to be recognized to inaugurate modifications. These changes are found to follow two lines; first, the use of a pump directly, and second, the indirect use of a pump to a small auxiliary fuel chamber from which the fuel is taken by the aspirating action of the vacuum that results from the flow of air through restricted inlet passages. The suction stroke of the engine induces a flow of air through the air passages to the cylinder and may be made to actuate an air motor driving a fuel pump to constitute a proportioning flow carburetor, as described in the cases of class 2. Proportionality is to be secured with this kind of apparatus by the relation between the fuel volume displacement of the pump and the air volume passing through and actuating the air motor. The pump may draw fuel directly from a main tank at a lower level than the engine, or from a small auxiliary tank or chamber kept supplied by a second feed pump, or the pressure supply may be retained. From such a small auxiliary tank or chamber, maintained automatically at a constant level by float valves, diaphragm valves, or overflow pipes, and supplied from a low level main tank by a feed pump or from a pressure supply, the fuel may be caused to flow into the air by the

vacuum developed in the latter by its flow, the fuel inlet to the air being above the fuel level in the constant level chamber.

This is a reasonably logical step and may be carried out with the same manually adjusted, but otherwise fixed and constantly open, air and fuel inlets used previously with pressure-fuel supplies, modeled on the gas mixer for hit-and-miss gas engines, but omitting the periodic fuel valve as not needed because of the aspiration principle. In this way the aspirating proportioning-flow carburetors with single fixed inlets were started, and their various forms are illustrated by the cases of class 3 and its subclasses. These are still in use and improvements in them are still appearing. For engines that take a substantially constant charge per stroke or that are attended by operators capable of modifying the adjustment when the charge per stroke must be materially changed, they are good enough, otherwise they are not satisfactory. They are now divisible into two groups with reference to the constant-level chamber and its fuel supply, which division does not affect their proportionality characteristics at all, the stationary-engine group almost universally, but not quite, uses an overflow cup, supplied by a constant displacement engine-driven pump from an underground tank, while the transportation engine, when it uses this sort of carburetor at all, is provided with a pressure supply of fuel to a float chamber; this is the case with marine engines, but some tractors, especially those with the hit-and-miss control, still use the pump and overflow cup.

If the gasoline engine requiring a graduation of supply per suction stroke and taking a charge for every such stroke, graduated in quantity to both its load at constant speed and to its speed at any load, had not been developed, there would never have been any real carburetor problem. The wide variations in number and size of cylinder, with their corresponding changes in suction pulsations added to the variations of flow rate due to both load and speed, make the problem a real and difficult one. Without the present-day necessity of constant mixtures, not only for stationary engines requiring close speed regulation at all loads, to be secured only by throttle governors imposing widely varying flow rates on their carburetors, but also for transportation engines of the marine, railroad, automobile, tractor, and aero classes, requiring wide variations in both speed and torque, with correspondingly wide variations in carburetor-flow rates without changing the mixture proportions, the carburetor would undoubtedly have remained a chamber with two fixed or adjustably fixed holes, one for fuel and one for air. Such a thing as a carburetor is quite useless for variable flow service even with a fuel of constant physical properties used at a constant altitude or barometric pressure and under constant air and fuel temperatures. Eliminating these last factors, there still remains a problem of very considerable magnitude and great difficulty, the design of variable flow-proportioning carburetors, and no better illustration of this difficulty can be found than the complexity and large number of the patents on the subject, on the one hand, coupled with the still present operator's difficulties with the commercial products of the present day, on the other.

All the cases from class 4 to class 14, inclusive, are concerned with various means of establishing and maintaining the proportionality

in variable-flow carburetors without any effort at automatic control or correction for densities or fuel viscosities, to which subject but little attention has as yet been paid, as is indicated by the few cases of class 15. The effort to solve the problem of the proportioning-flow carburetor used with varying-flow rates is more or less logically analyzed by the new class groupings with their various subclasses, all of them starting with the now well-known assumption of fact, that no single fixed fuel inlet and single fixed air inlet will suffice, the ratio of fuel to air increasing regularly or irregularly with increase in flow rate in such a structure.

To correct this tendency toward an increasing percentage of fuel in the mixture with increasing flow rates, structural modification of the two simple fixed inlets is necessary, and these modifications are divisible into two groups. It is clear that once the mixture has become overrich after an increase in flow rate, the original proportion can be restored, first, by reducing the vacuum at the fuel outlet through an increase of the air inlet by a graduating valve or a movement to a point of less velocity, or by reducing the pressure on the fuel surface in the constant level cup, or in general the net fuel-flow head, and, second, by reducing the area of the fuel inlet by a graduating valve. These two ways of compensation are typical of the two broad group divisions—first, compensation by control of fuel-flow head; second, compensation by control of fuel-flow area. Of course, both may be utilized at the same time, and in any one carburetor many of the several different means of accomplishing both are found operating simultaneously. It should be noted that the primary or basic way of controlling fuel-flow head is by the air vacuum at the fuel inlet without operating on the surface pressure of the fuel in its constant level chamber, and this control of vacuum at the fuel inlet to the carburetor is a matter of air-inlet valve area, number and location of inlets, though subject to some control by variations in internal position of fuel inlet or direction of the air flowing past it. The fundamental basis of all proportionality control in carburetors is, therefore, one of structural arrangement of fuel and air inlets, in number, location, and relative area adjustment, corresponding to change of flow rates. This idea is incorporated in the new classification where the several classes are distinguished one from another by the number of fuel or air inlets and by the presence or absence in them of a regulating valve to adjust the flow area of either to the flow rates. Subclasses include either important groups of special cases of the general class or cases of some additional means of fuel-pressure control above that afforded by the air-inlet arrangements of the general class. For example, classes 3 to 10, inclusive, all have fixed, nonvarying fuel-inlet areas in any number associated in classes 3 and 6, inclusive, with any number of fixed air inlets, and in classes 7 to 10, inclusive, with variable air inlets in any number, the air-inlet graduating valve being actuated in different ways in the several subclasses. Similarly, classes 11 to 14, inclusive, are all cases of variable fuel-inlet areas, where fuel graduating valves are used and actuated in the several subclasses in each of the typical ways. These several classes of variable fuel inlets are associated in class 11 with fixed air inlets in any number, and in classes 12 to 14, inclusive, with variable air inlets, having graduating valves.

Within any one class characterized by a specified number of air and fuel inlets, fixed or variable, the subclasses will indicate additional or special means of fuel-pressure variation with flow as, for example, float-chamber pressure control, which may be used with any combination or kind of inlets; likewise, mixed flow or the admission of a small amount of air to the fuel passage to break the vacuum to the necessary extent, the air and fuel flowing together mixed. Again, in each of the several classes of multiple fixed fuel inlets there may be a subclass for the special form of the fuel standpipe in which successive holes or outlets are brought into action as the vacuum increases somewhat equivalent to a varying fuel-inlet area, though only as head increases and as a result of it. Finally, in the several classes of multiple fuel there may appear subclasses representing two or more complete carburetors, each of another simpler class all the same, and brought into action successively to limit the flow variation in any one set of passages and thereby limit the necessity for the other sorts of compensation that are necessary with wider variations of flow in one; 10 such carburetor units in one multiple carburetor would limit the flow variations in each member to one-tenth as much as in a single similar one for a given total range of flow rates.

With this introduction on the general problem and plan of investigation of the efforts of inventors to solve it, as disclosed in the patent art, the several new classes and subclasses will be examined separately.

Class 1, carburetors, proportioning flow, fixed air and fuel inlets, periodic fuel valve.—This is the early developed class of carburetors designed to convert a gas engine into a gasoline engine by an almost identical device, smaller in proportion to the relative volumes of gasoline to gas for the same amount of air, and primarily intended for hit-and-miss stationary engines requiring no graduation of flow, and for pressure supplies of fuel, that require a shut-off valve to stop the flow between suction strokes. When this stop valve is open, the flow effect is that of a fixed fuel passage. This fuel valve, with or without a corresponding air valve, may be actuated in any one of several ways to be noted, primarily adapted to reasonably low-speed engines, and normally to a single cylinder, or to one such carburetor per cylinder.

One early case of a fuel valve actuated by an air-flow impact disk, movement of which does not affect the area of the air-flow passage, is shown on page 175 (581,930, May 4, 1897, Alderson), which illustrates the idea of alternative use in a similar way, of gas and gasoline, because a gas inlet is also provided with its own valve to be opened by the vacuum directly because it is large enough. This case also illustrates a different means of fixing and adjusting the fuel inlet area by limiting the lift of the fuel valve, the shoulder of which strikes the end of an adjustable sleeve. In this case the fuel is discharged into a freely open portion of the air inlet where the vacuum is negligible and the gooseneck fuel-supply pipe rising above the fuel valve indicates the intention to use a pressure supply of fuel under at least this much head. An air-flow disk located at the throat of a double-tapered air passage with another such disk on the same stem at the large diameter point immediately above it,

to produce the double effect of a prompt lift of the fuel valve formed at the end of the stem, and to spatter the fuel so it may mix with the air in the irregular passage, is the construction illustrated on page 176 (584,666, June 15, 1897, Bollee). Not only is this case interesting because of the construction but also because the patent is for a "motor vehicle," and is one of the early constructions of this, at the time, very new art. While the fuel valve is located in front of the air-inlet valve and is, therefore, subjected to none of the vacuum due to air-entrance resistance, it is nevertheless, by reason of the air-passage taper, subjected to the vacuum of the air velocity head, and the case is one of the very early examples of the use of velocity-head vacuum to influence fuel flow.

As showing the use of a pressure supply of fuel, the case on page 177 (611,341, Sept. 27, 1898, Starr & Cogswell) is interesting, because the elevated chamber is shown feeding the tubular fuel valve, the seat of which is lifted off by the entrance air valve beyond. As the fuel flows down it meets the air rising, but evidently complete vaporization was not regarded as assured, because a drainpipe is provided joining the cup overflow.

Location of a fuel valve on the supply side of an automatic air check valve is also illustrated on page 177 (688,367, Dec. 10, 1901, Tregurtha), which also shows a broad enlargement below the fuel inlet, over which the measured amount of fuel is intended to be evaporated by the air, a thing that could not be done at all with present-day gasoline. A contrary fuel flow arrangement with the same location of fuel valve on the supply side of the air check is shown on page 177. Here the fuel flows down with the air toward the cylinder. (703,937, July 1, 1902, Lizotte.) Use of a piston type of air valve to actuate the fuel valve is shown on page 178 (705,021, July 22, 1902, Bennett & Morewood) to avoid the difficulty of simultaneously making tight an air check and a rigidly attached fuel valve. A similar purpose is served by the spring of 703,937, July 1, 1902, Lizotte. Actuation of the fuel valve by the vacuum directly is shown on pages 177 and 178 (705,314, July 22, 1902, Blake), the diapraghm C rising with the vacuum and opening the fuel valve. This case also illustrates the use of primary and secondary air through two separate air inlets.

An illustration of a form especially adapted to the hit-and-miss engine is given on pages 178 and 179 (722,672, Mar. 17, 1903, Burger), where a governor controlled pawl carried on a sleeve about the air valve stem opens or does not open the fuel valve.

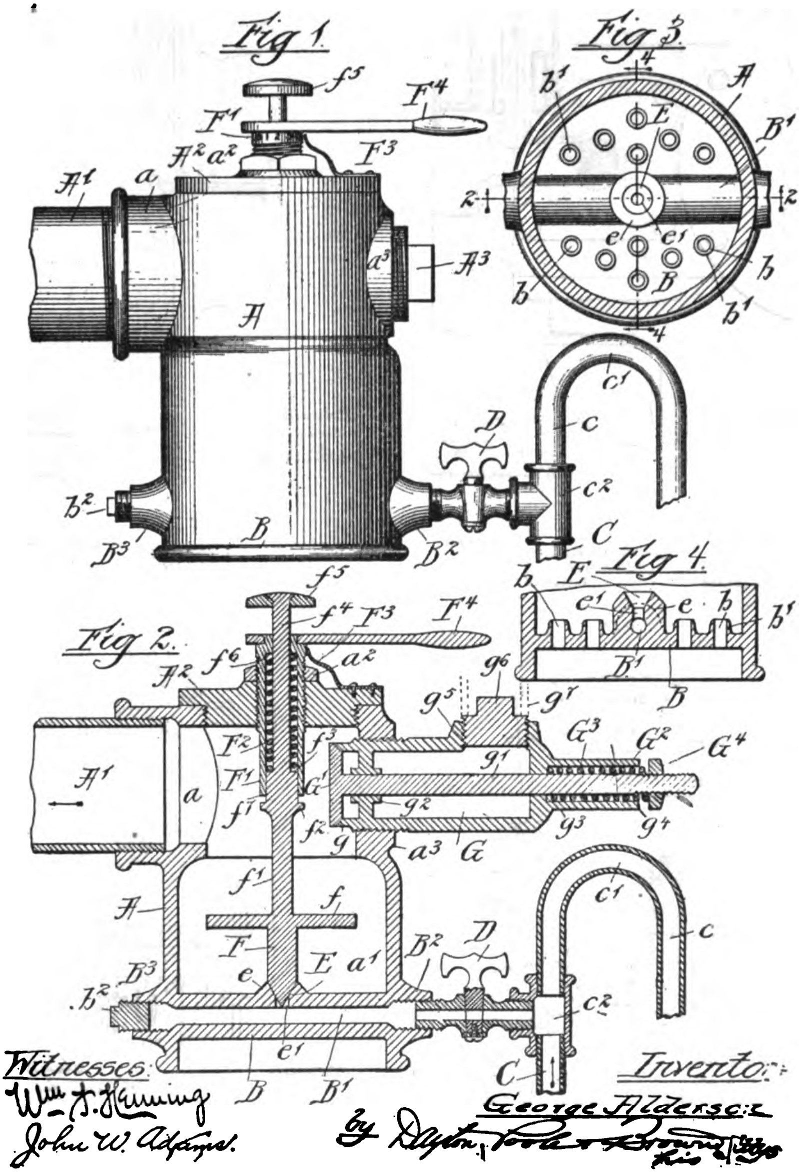
Direct attachment of the fuel valve to the main engine inlet is shown on page 179. (724,328, Mar. 31, 1903, Pivert.) Another case of air impact disk actuating the fuel valve is shown on page 179 (747,235, Dec. 15, 1903, Saris) in connection with two other interesting features, one, the constant level float chamber, the level in which is above the fuel valve, making the valve necessary, and the other, the hollow stem of the fuel valve, which accumulates fuel between suction strokes, discharging the accumulation with whatever comes past the regular needle valve. This is a sort of forerunner of the now common accelerating cup of modern carburetors that accumulates fuel during periods of low engine demand, discharging it quickly on a sudden increase in demand due to the opening of the throttle at a time when the mixture would otherwise tend to become lean by reason of the greater inertia of the fuel over the air.

(No Model.)

G. ALDERSON.

GAS MIXER.

No. 581,930 Patented May 4, 1897.

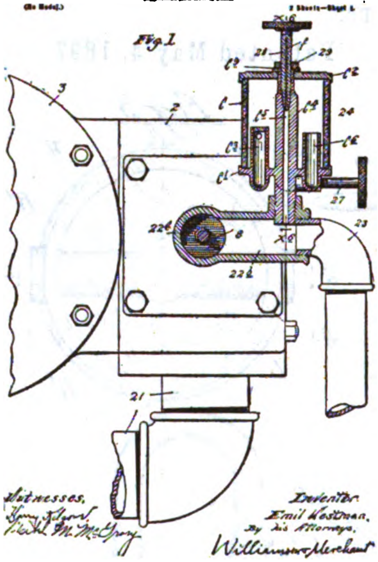


No. [illegible] E. WESTMAN. Patented Aug. 27, [illegible]

FEED CUP FOR EXPLOSIVE ENGINES.

(Application filed [illegible])

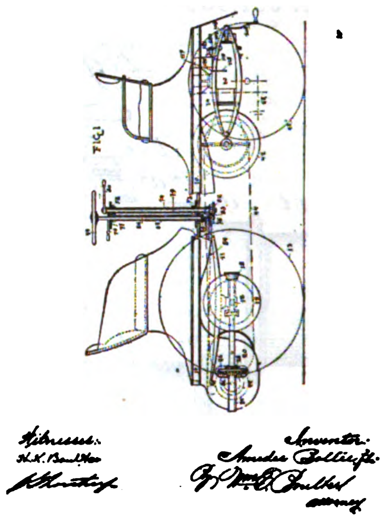
(No Model.) 2 Sheets—Sheet 1.



(No Model.) A. BOLLÉE, FILS. 3 Sheets—Sheet 1.

MOTOR VEHICLE.

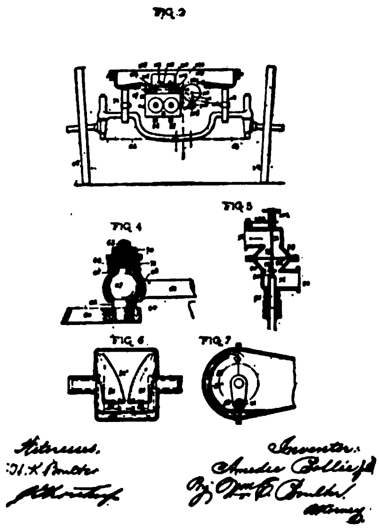
No. 584,666. Patented June 15, 1897.



(No Model.) A. BOLLÉE, FILS. 3 Sheets—Sheet 2.

MOTOR VEHICLE.

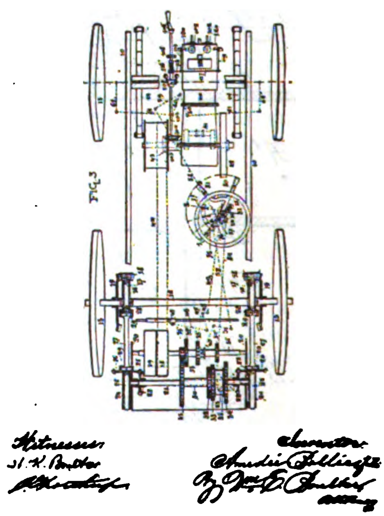
No. 584,666. Patented June 15, 1897.



(No Model.) A. BOLLÉE, FILS. 3 Sheets—Sheet 3.

MOTOR VEHICLE.

No. 584,666. Patented June 15, 1897.



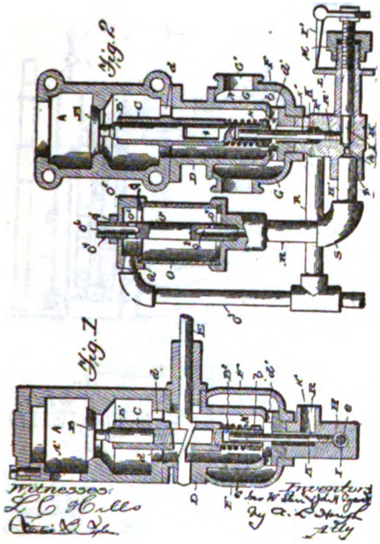
No. [illegible] Patented Sept. 27, [illegible]

G. W. STAGE & J. E. COGSWELL.

MIXER AND VAPORIZER FOR EXPLOSIVE ENGINES.

(Application filed [illegible])

(No Model.)



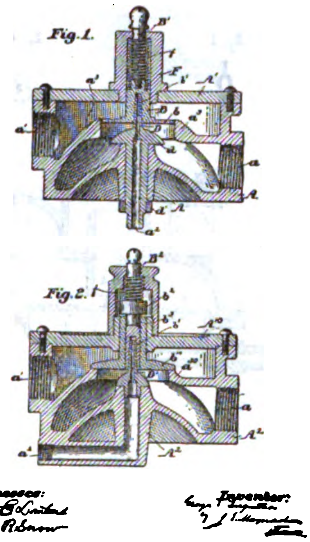
No. [illegible] Patented Dec. [illegible]

G. E. TREGURTHA.

VAPORIZER FOR GASOLENE ENGINES.

(Application filed [illegible])

(No Model.)



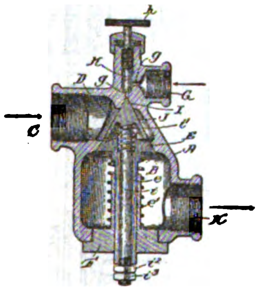
No. 70[illegible] Patented July [illegible], 1902.

J. LIZOTTE.

VAPORIZER FOR EXPLOSIVE ENGINES.

(Application filed [illegible])

(No Model.)



Witnesses.

Inventor.

No. 70[illegible] Patented July 22, 1902.

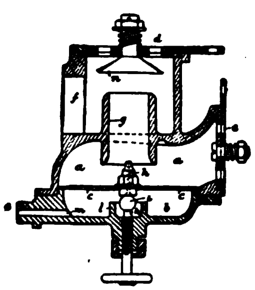
F. C. BLAKE.

CARBURETER.

(Application filed [illegible])

(No Model.) [illegible] Sheets—Sheet [illegible]

Fig. 1



Witnesses

Inventor

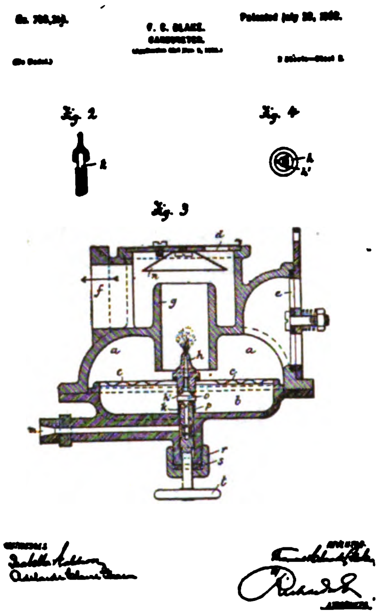
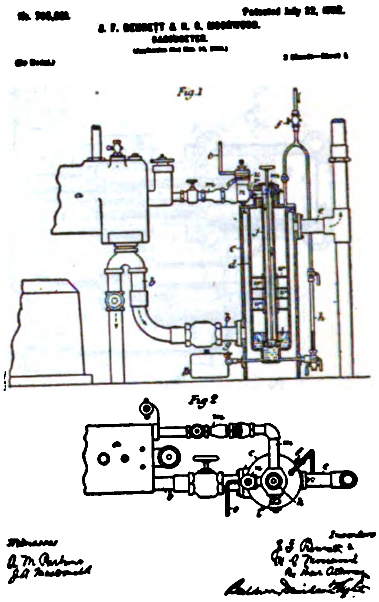
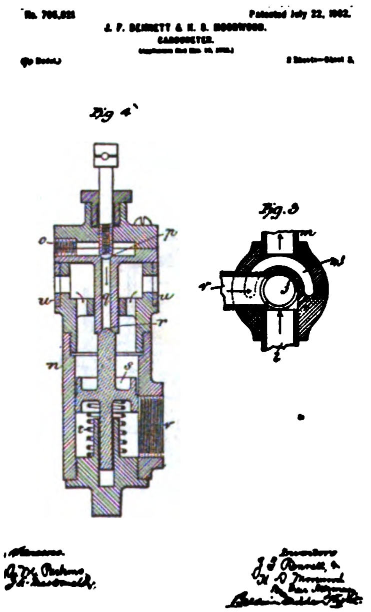
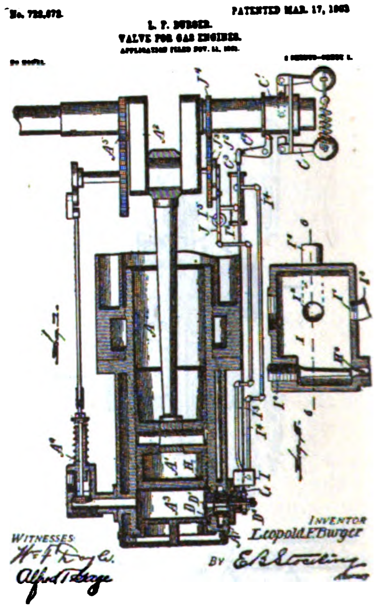


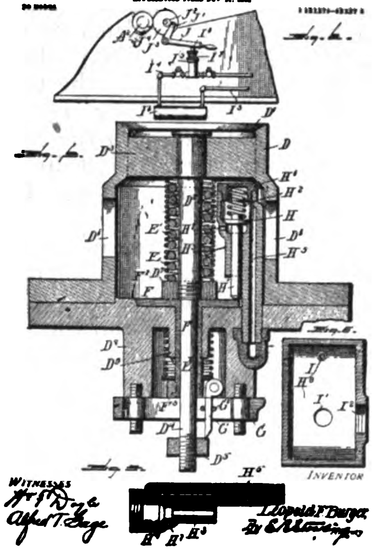
Fig. 2
Fig. 4
Fig. 3


Patented July 22, 1902.
CARBURETER.
Fig.1
Fig.2

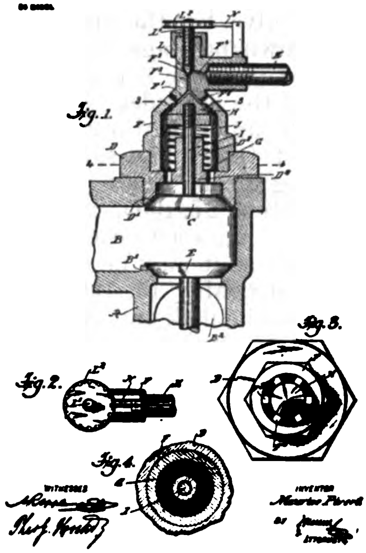

Patented July 22, 1902.
CARBURETER.
Fig 4


PATENTED MAR. 17, 1903
L. P. BURGER.
VALVE FOR GAS ENGINES.
WITNESSES
INVENTOR
Leopold F. Burger
BY

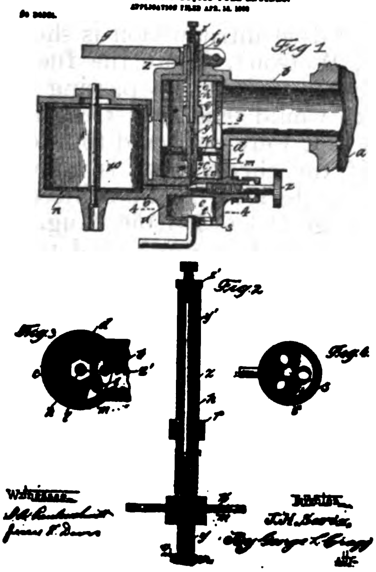
No. 7[illegible] PATENTED MAR. 17, 190[illegible].
L. F. BURGER.
VALVE FOR GAS ENGINES.
APPLICATION FILED NOV. 11, 190[illegible].
NO MODEL.



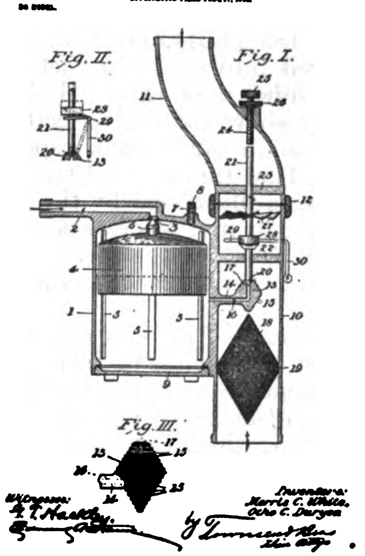
No. [illegible] PATENTED MAR. 31, 190[illegible].
M. PIVERT.
MIXING VALVE FOR EXPLOSION ENGINES.
APPLICATION FILED [illegible]
NO MODEL.



No. 747,2[illegible]. PATENTED DEC. 15, 190[illegible].
J. H. SARIS.
CARBURETER FOR LIQUID FUEL ENGINES.
APPLICATION FILED APR. 1[illegible], 190[illegible].
NO MODEL.



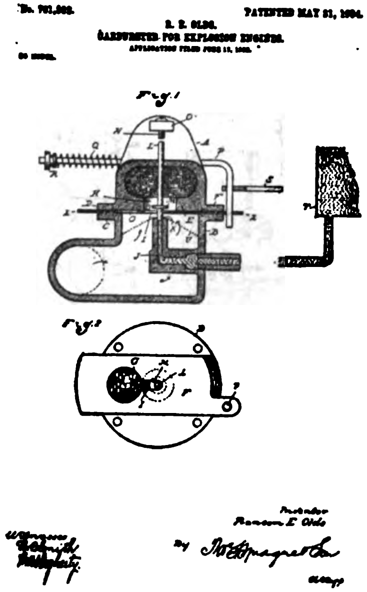
No. 7[illegible]. PATENTED MAY 2[illegible], 190[illegible].
M. C. WHITE & O. C. DURYEA.
VAPORIZER FOR EXPLOSIVE ENGINES.
APPLICATION FILED JUNE 1[illegible], 190[illegible].
NO MODEL.

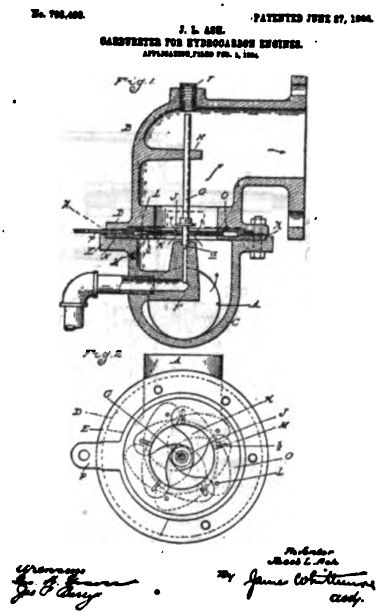


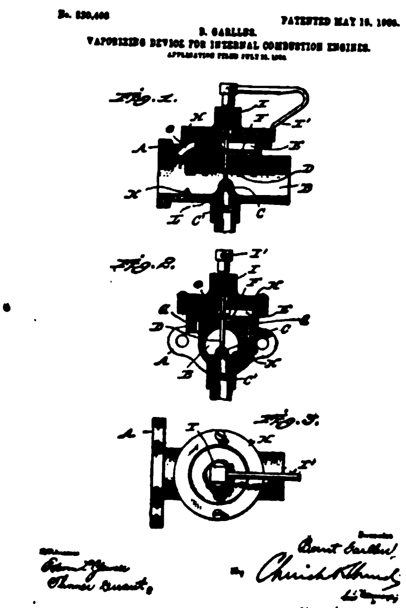
The use of a fan type of air motor as an air impact device to lift the fuel valve is illustrated on page 179 (760,673, May 24, 1904, White & Duryea), the fan or motor also serving as a mixer. Adjustment of proportions in those cases so far illustrated has been provided by a needle valve before the fuel inlet valve or by limiting the lift of the inlet valve, but the same result may be obtained by adjusting the air as shown on page 181. (761,392, May 31, 1904, Olds.) Here the use of pressure supply of fuel is clearly indicated by the tank level, and the air inlet is provided with an area adjusting slide to control the amount of air that shall enter each stroke with the fixed amount of fuel. The same idea of control by the air, but by an interesting form of air damper, the iris, is shown on page 181. (793,498, June 27, 1905, Ash.)

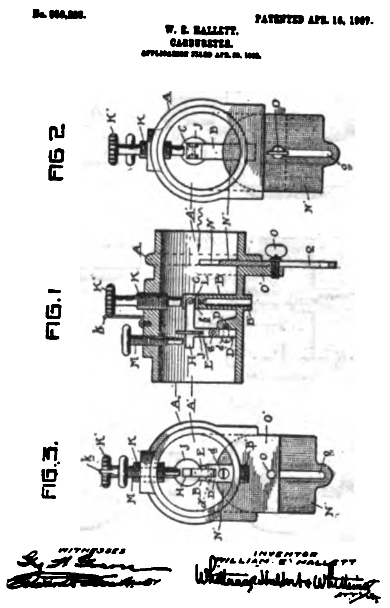
Direct vacuum actuation of the fuel valve, independent of the air flow except as it may be the cause of the vacuum, is shown on page 181 (820,408, May 15, 1906, Garllus), where the vacuum acting on one side of the disk and atmosphere on the other, lifts it and the fuel valve. A pivoted or swing type of air-flow disk to actuate the fuel valve is shown on page 181 (850,223, Apr. 16, 1907, Hallett), a form that should be very sensitive to air movements and sure to open fully each time. A form in which the check valve that actuates the fuel valve does so by an indirect connection is shown on page 182 (999,033, July 25, 1911, Hubbard), where a lever permits relative lifts about in proportion to the two valve diameters, which is not possible with direct axial connection, except by making the period of opening of the air valve greater than that of the fuel valve. A ball used as the fuel valve and lifted by the vacuum directly is shown on page 182 (1,004,091, Sept. 26, 1911, Shain), and a similar use of direct vacuum on a flat-faced valve is shown on page 182 (1,120,397, Dec. 8, 1914, Martin). An interesting case of indirect fuel introduction is shown on page 182 (1,044,314, Nov. 12, 1912, Watson), where the fuel is discharged into a side pocket with an air passage by passing the spring-loaded inlet valve. This passage would tend to lift the fuel promptly above that valve, better than if it were delivered to a low-velocity main air stream, especially if the check valve is heavily loaded. That this old and simple class of device is still a subject of invention is illustrated by the case on page 183 (1,151,156, Aug. 24, 1915, Bingaman), where a simple air-flow disk causes a fuel valve to lift in front of the air, or in this case, the mixture-inlet valve, here used as the entrance to the closed crank case of a small two-cycle engine.

Subclass 1.1—Fuel valve operated by engine valve gear.—Probably the oldest of the class of fuel valves directly operated from the valve gear, independent of the air or mixture valves, and under the control of a hit-and-miss governor, is that on page 184 (433,806, Aug. 5, 1890, Otto), which case is of peculiar interest, in view of the pioneer work of this now famous inventor, Otto, a contemporary and rival of the equally famous Körting. One other case will serve to illustrate this subclass as it is of such limited value in its bearing on the general problem, that on pages 184 and 185 (574,183, Dec. 29, 1896, Underwood), where by the one cam-actuated arm, the main inlet valve is lifted, and at the time a gas, and a gasoline fuel valve as well.


PATENTED MAY 31, 1904.
CARBURETER FOR EXPLOSION ENGINES.
Fig. 1
Fig. 2

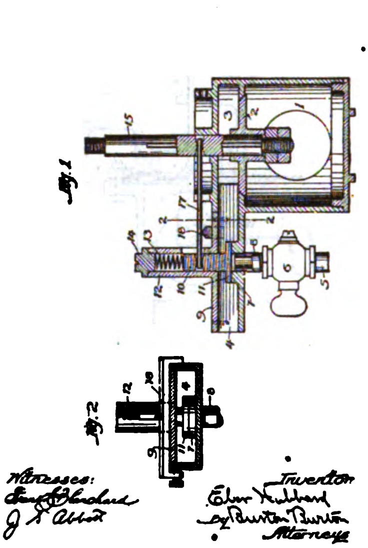

CARBURETER FOR HYDROCARBON ENGINES.
Fig. 1
Fig. 2


VAPORIZING DEVICE FOR INTERNAL COMBUSTION ENGINES.
Fig. 1.
Fig. 2.
Fig. 3.


PATENTED APR. 16, 1907.
W. E. HALLETT.
CARBURETER.
FIG 2
FIG. 1
FIG. 3.
WITNESSES
INVENTOR
WILLIAM E. HALLETT

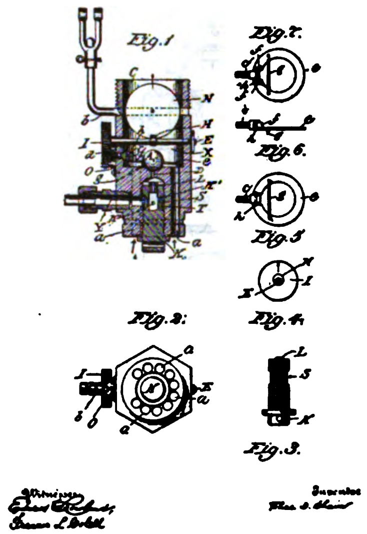
E. HUBBARD.
[illegible] SUPPLY VALVE.
APPLICATION FILED [illegible]

999,083. Patented July 25, 1911.



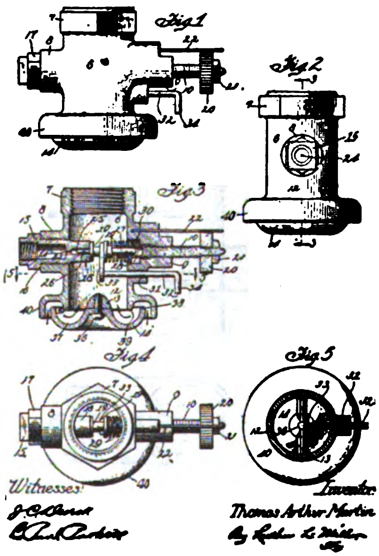
G. D. SHAIN.
CARBURETER FOR GAS ENGINES.
APPLICATION FILED [illegible]

1,004,091. Patented Sept. 26, 1911.



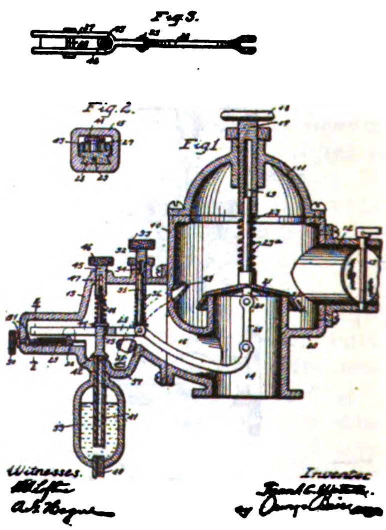
T. A. MARTIN.
CARBURETER.
APPLICATION FILED [illegible]

1,120,397. Patented Dec. 8, 1914.

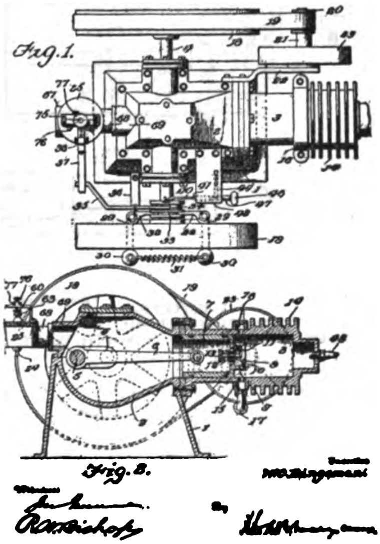


F. C. WATSON
CARBURETER.
APPLICATION FILED [illegible]

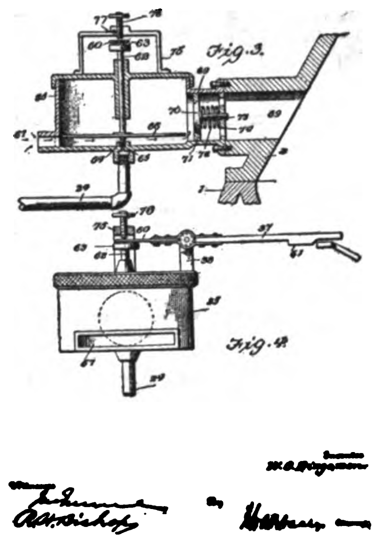
1,044,314. Patented Nov. 12, 1912.

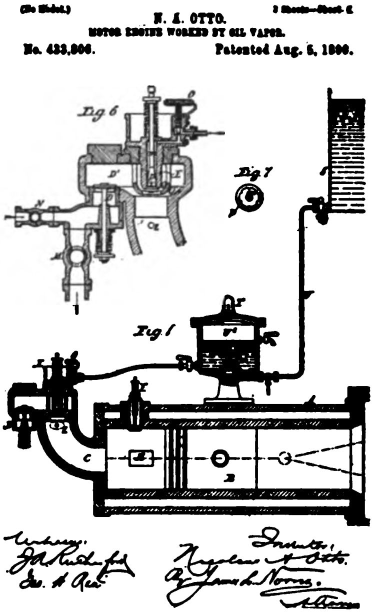


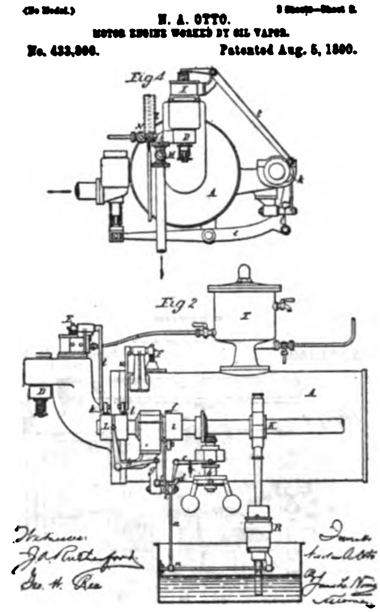
1,151,158. Patented Aug. 24, 1915.

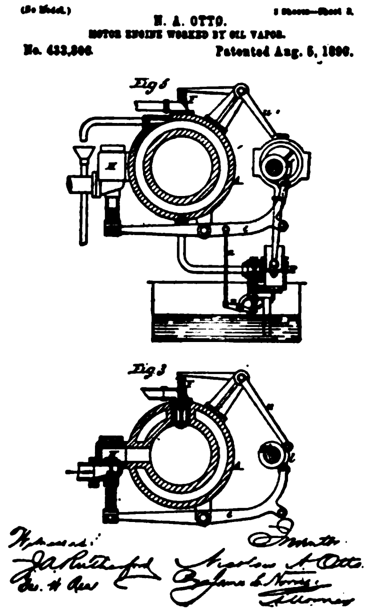


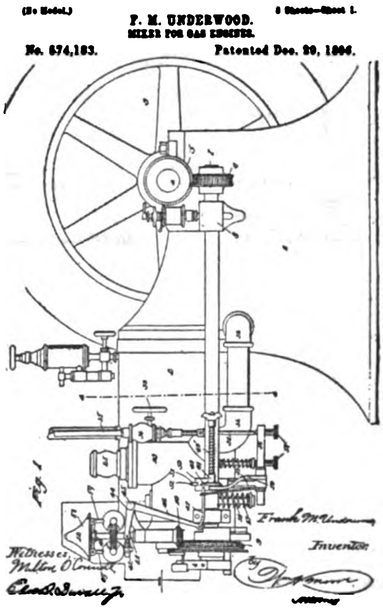
1,151,158. Patented Aug. 24, 1915.



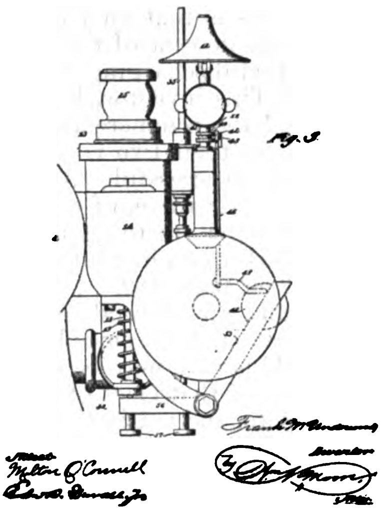

(No Model.) 3 Sheets—Sheet 1.
N. A. OTTO.
MOTOR ENGINE WORKED BY OIL VAPOR.
No. 433,806. Patented Aug. 5, 1890.
Fig 6
Fig 7
Fig 1
Witnesses:
Inventor:
Nicolaus A. Otto
Attorney


(No Model.) 3 Sheets—Sheet 2.
N. A. OTTO.
MOTOR ENGINE WORKED BY OIL VAPOR.
No. 433,806. Patented Aug. 5, 1890.
Fig 4
Fig 2
Witnesses:

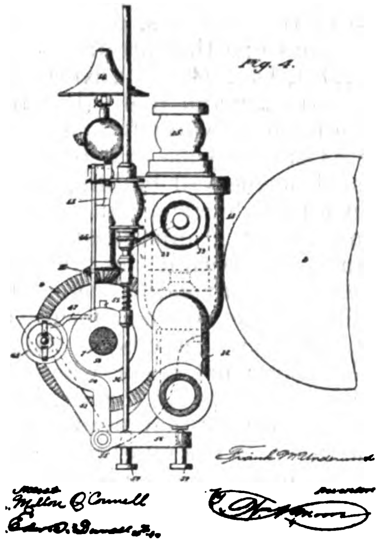

(No Model.) 3 Sheets—Sheet 3.
N. A. OTTO.
MOTOR ENGINE WORKED BY OIL VAPOR.
No. 433,806. Patented Aug. 5, 1890.
Fig 5
Fig 3
Witnesses:
Inventor
Nicolaus A. Otto
Attorney


(No Model.) 6 Sheets—Sheet 1.
F. M. UNDERWOOD.
MIXER FOR GAS ENGINES.
No. 574,183. Patented Dec. 29, 1896.
Fig. 1
Frank M. Underwood
Inventor
Witnesses,
Milton O'Connell
Attorney

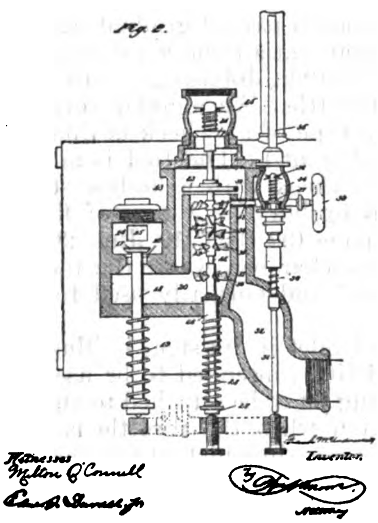
(No Model.) F. M. UNDERWOOD. 5 Sheets—Sheet 3.
MIXER FOR GAS ENGINES.
No. 574,183. Patented Dec. 29, 1896.



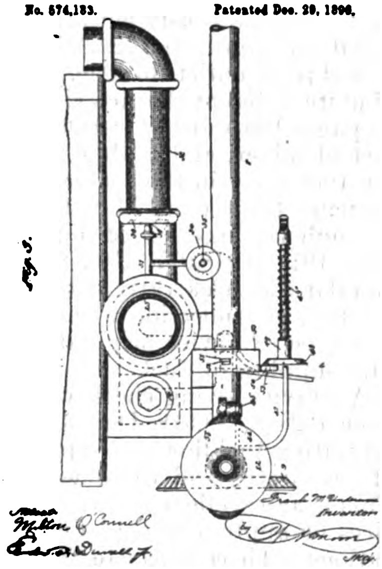
(No Model.) F. M. UNDERWOOD. 5 Sheets—Sheet 4.
MIXER FOR GAS ENGINES.
No. 574,183. Patented Dec. 29, 1896.



(No Model.) F. M. UNDERWOOD. 5 Sheets—Sheet 2.
MIXER FOR GAS ENGINES.
No. 574,183. Patented Dec. 29, 1896.



(No Model.) F. M. UNDERWOOD. 5 Sheets—Sheet 5.
MIXER FOR GAS ENGINES.
No. 574,183. Patented Dec. 29, 1896.



Subclass 12—Fuel inlet in seat of automatic air inlet valve.—The idea of this arrangement in this class is to insure an adequate air velocity past the fuel inlet when it opens to carry the fuel and prevent it dropping back, but there may be some difficulty in making a broad seat of a conical air check valve close tightly an appropriately small fuel inlet, and even as much so with flat seats. The earliest case of this subclass, perhaps also the earliest of the whole general class, and one that attained commercial success is that on page 189 (417,924, Dec. 24, 1889, Körting), in which the descent of the piston opens the air and fuel valves together, the fuel discharging into the seat of the air valve for vigorous spraying. This inventor, Körting, with Otto, may be said to have inaugurated the commercially successful business of building gasoline engines in their two rival German establishments, still in existence and still successful. Association with a fuel inlet located in the seat of the air valve, of a heated chamber, to permit the same proportioning structure to operate on a heavy or nonvolatile fuel, and thus to convert a gasoline into an oil engine, to use common terms, is illustrated on page 189. (523,511, July 24, 1894, Campbell.) Here the fuel and air descend together and strike a hot elbow where the oil separates out, becomes heated, and being swept by the air, is vaporized. This case may be said to have practically inaugurated the construction of that class of oil engine in which the mixture is made externally to, and not in the cylinder, by first proportioning fuel and air, and then heating the mixture on its way to the cylinder. Another early form of this arrangement is shown on page 189 (635,166, Oct. 17, 1899, Hay), which also provides exhaust heat for the fuel and mixture entrance chamber. A complete ring of fuel inlet holes is shown in the form on page 190. (690,112, Dec. 31, 1901, Kull.) Manual adjustment of the fuel needle valve simultaneously with the lift limit of the air check valve, is provided on page 190 (722,357, Mar. 10, 1903, Davis), which, if connected to an outlet throttle, would become a pair of graduating valves of quite different characteristics. A flat seat air check valve is shown on pages 190 and 191 (894,656, July 28, 1908, Johnston), with an odd sort of mixer, and a plug form of throttle. An annular form with the fuel valve in the center of piston type of air check is illustrated on page 191. (922, May 18, 1909, Wright.) The fuel is admitted through the interior of a hollow air check with a hollow stem on page 191. (948,977, Feb. 8, 1910, Kingsbury.) A case of flat seat annular air check valve is shown on page 192 (995,919, June 20, 1911, Smith), in connection with a fuel float chamber, where the fuel inlet is a type of device originally designed and normally used for pressure supplies of fuel.

A gravity swing check with a fuel inlet in its stem is illusted on page 192 (1,048,518, Dec. 31, 1912, Fritz), intended to be used with aspirating fuel flow as a separate idling jet to be attached to any form of carburetor and to come into action when the throttle is closed. This is an excellent illustration of the way in which old forms of devices or appliances may find new uses or be revived in new combinations. Three separate fuel inlets in the air check-valve seat, one for gasoline, one for kerosene, and a third for water, are illustrated

on pages 192 and 193 (1,156,836, Oct. 12, 1915, Diener), in connection with an exhaust heated vaporizer, for an engine to be started on gasoline, and when heated operated on kerosene, the water being added to control preignitions.

Subclass 1.3—Fuel inlet located beyond automatic air inlet.—One early case (500,401, June 27, 1893, Lehman), shown on page 194, attaches the fuel valve to a spring-closed poppet air-inlet valve by a yoke with a flexible element, the fuel inlet being located so that it is acted upon by the vacuum which opens the air valve, so the fuel valve must be affected correspondingly. This is in contrast to the last subclass where the air velocity over its valve seat, and not the vacuum beyond the seat, acts on the fuel inlet. The form shown on page 194 (515,059, Feb. 20, 1894, Hoyt) illustrates the use of a slide valve for the fuel, actuated by the automatic air valve. The location of the tank clearly indicates a pressure fuel supply. A swing air check that strikes a separate spring-closed fuel valve is shown on page 194 (567,253, Sept. 8, 1896, Pratt), and another swing check striking a gravity and pressure closed fuel valve on page 195 (609,557, Aug. 23, 1898, Phelps). That the point of mixture of fuel and air may be controlled independently of the valve locations is illustrated on page 195 (616,974, Jan. 3, 1899, Riotte), where, although the fuel valve is formed on the end of the air-valve stem, the fuel meets the air at a distant point, emerging in four streams at a contraction to promote mixing. An independent fuel check acted on by the vacuum developed beyond the automatic air valve is shown on page 195 (617,743, Apr. 9, 1901, White) in connection with a constant-level chamber having an outlet below the level but sealed by a ball. Another case of a heater associated with proportioning fuel and air inlets is that on pages 195 and 196 (619,776, Feb. 21, 1899, Murray), in which the air valve by a long extension of its stem opens a distant oil valve, oil and air entering a heated annular pot at separate points, with the idea of promoting vaporization of the oil and mixing of its vapor with the air after the proportions have been established by the same means commonly used for gasoline and air. Another independent fuel check valve of swing type similarly located with reference to the air check but above the level in an overflow chamber, so the fuel is aspirated, is shown on page 196 (694,708, Mar. 4, 1902, White). A lever connection between the automatic air valve and a fuel valve located beyond it is shown on page 196 (1,066,080, July 1, 1913, Cole) with a hand-adjusted needle valve. This is particularly interesting because of its general similarity to another later class. If the fuel valve were given a longer taper and the air valve were situated in a long tapered seat the flow areas of the two could easily be kept in any desired ratio and proportionality be established with but little vacuum change. Such cases are fairly numerous in the later classes where the fuel is provided with a graduating valve controlled by an automatic air valve, main or secondary.

Subclass 1.4, double air inlet, one air inlet by-passes fuel inlet.—This class is the forerunner of the very large class of primary and secondary air inlets with its various combinations of valves and interconnections. Apparently the idea, at least at first, was that of

spraying and mixing rather than that of a compensating arrangement to correct for the tendency to become excessively rich in fixed single air and fuel inlets, by admitting a secondary or diluting air stream. In a patent granted for a "self-propelling carriage," a fuel valve actuated by an air valve, makes what may be termed a primary mixture, to which additional or secondary air may be admitted for a manual adjustment of proportions, as shown on page 197. (610,460, Sept. 6, 1898, Pretot.) One early form, that on page 197 (679,387, July 30, 1901, Mathieu), has a pair of air-impact disks by which the fuel valve is actuated, air from one inlet strikes the top disk and opens the fuel valve, the fuel being spread over the disk and sprayed down from its edge in front of the second air stream. This may be compared with the form on page 197 (715,398, Dec. 9, 1902, Longuemare), which is really intended to act in the compensating way, the secondary air being admitted beyond the impact hood equivalent to a disk, so that the fuel valve is lifted for a shorter period and fuel admitted less, the more the secondary air. Secondary air acts, therefore, to limit the fuel lift somewhat, but not quite as would a mechanical stop, and its effect on proportioning is similar to that of a fuel needle valve. In the form, page 198 (896,388, Aug. 18, 1908, Johnston), part of the air passes directly up the center tube, exerting a velocity action at the fuel outlet and impinging on the fuel valve lifting disk, while the rest of the air enters around the edge of the automatic inlet valve, and has no influence in lifting the fuel valve at all, but a mechanical stop to limit the lift is also used. The fuel-air ratio is directly adjustable manually by the air by-pass, or by the fuel needle, in the form page 198. (903,206, Nov. 10, 1908, Lawson.) A still closer approach to the automatic compensating action of automatic secondary air is shown on page 198 (939,856, Nov. 9, 1909, Papanti), where the secondary air enters by an automatic valve. This, by the removal of the fuel valve and attachment to a constant level cup, would become one of the very large class of so-called automatic compensating cases of subclass 8.2. Indicating that carburetors of this class are still being brought forward is the case on page 198 (1,181,514, May 2, 1916, Eynon), in which the fuel valve purpose is not clear, because the flow is purely aspirating, but the perforated box surrounding the fuel outlet is intended to assist in spraying and mixing.

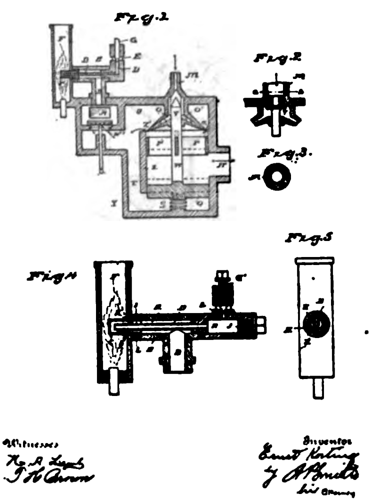
Class 2, carburetors, proportioning flow, metering fuel pump, air-motor driven.—For many years before the advent of the gasoline engine and the need in connection with it of suitably small, cheap, and accurately proportioning carburetors that would not leave heavy fractions as unusable residues the art of gas making had been pretty considerably developed, and in connection with it a very large number of evaporative carburetors. Some of these had fuel-feed valves more or less relating the control of fuel flow to that of air flow, but the great majority, substantially all of them, maintained a body of liquid either in bulk or spread over solid, porous, or fibrous surfaces, from which evaporation took place, the proportions being established by the evaporative conditions rather than by the conditions of feed and flow. From this, however, has come in a more or less logical

(No Model.)

E. KORTING

METHOD OF AUTOMATIC IGNITION IN GAS ENGINES.

No. 417,924 Patented Dec. 24, 1889.

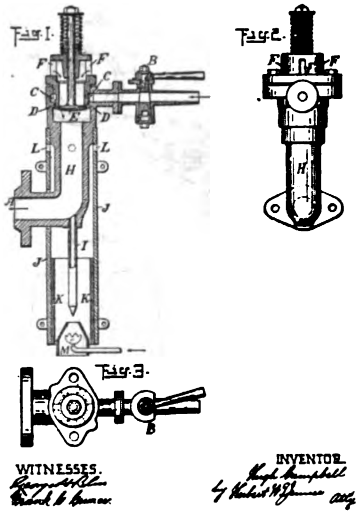


(No Model.) 2 Sheets—Sheet 1.

H. CAMPBELL.

OIL ENGINE.

No. 523,511. Patented July 24, 1894.

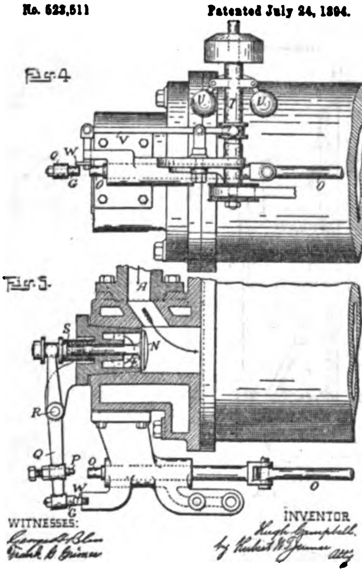


(No Model.) 2 Sheets—Sheet 2.

H. CAMPBELL.

OIL ENGINE.

No. 523,511 Patented July 24, 1894.



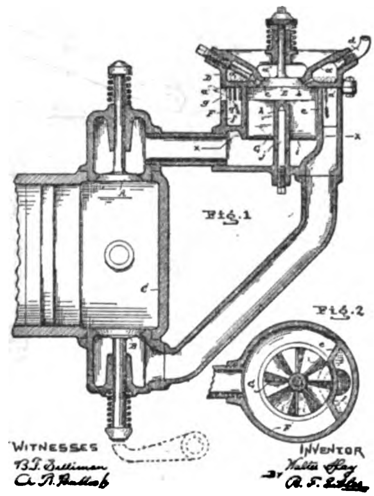
No. [illegible] Patented Oct. 17, 1899.

W. MAY

VAPORIZER FOR GAS ENGINES.

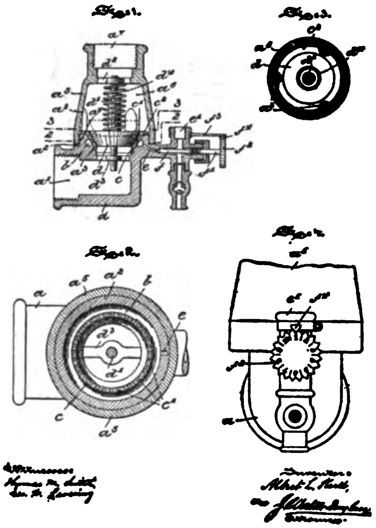
(Application filed [illegible])

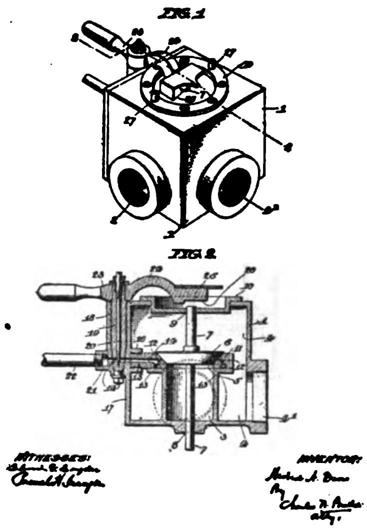
(No Model.)



PATENTED MAR. 10, 1903.

CARBURETER FOR GAS ENGINES.

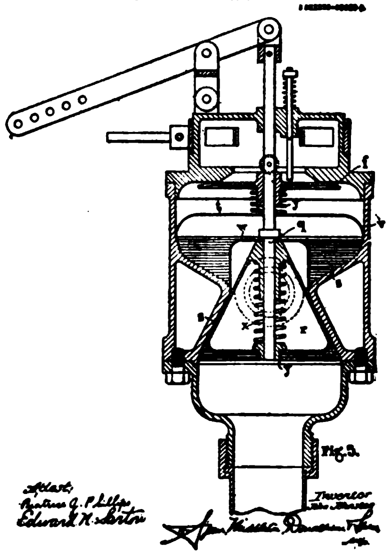


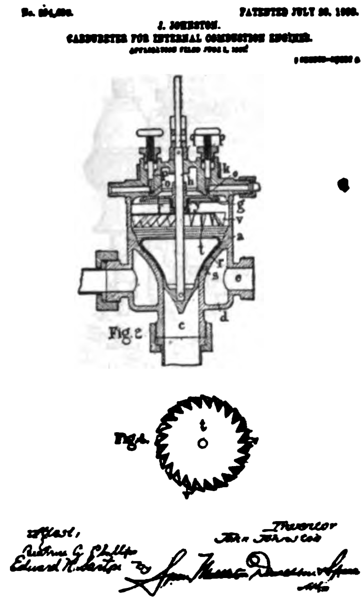


PATENTED JULY 28, 1908.

J. JOHNSTON.

CARBURETER FOR INTERNAL COMBUSTION ENGINES.




J. JOHNSTON.
Fig.2
Fig.4
Inventor

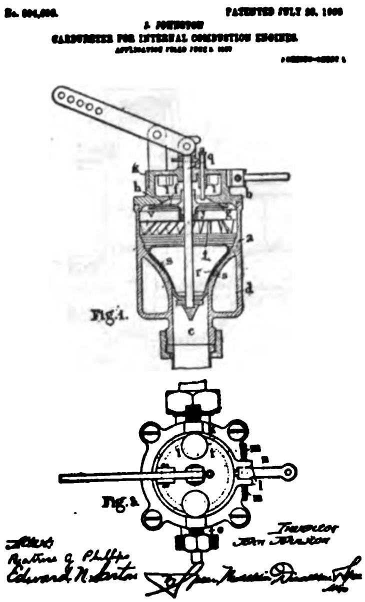
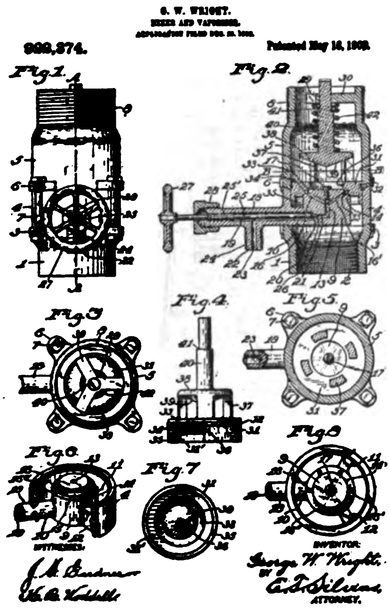
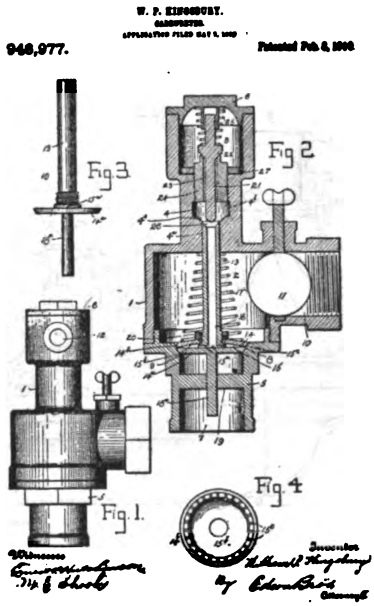


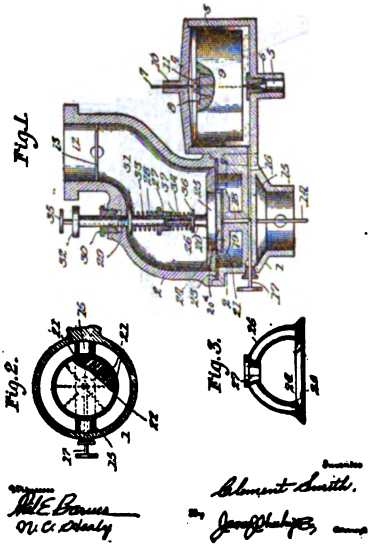
Fig.1
Fig.3
Inventor


G. W. WRIGHT.
Fig.1.
Fig.2.
Fig.3
Fig.4.
Fig.5.
Fig.6
Fig.7
Fig.8
WITNESSES:
INVENTOR:
George W. Wright.
ATTORNEY.


W. P. KINGSBURY.
948,977.
Fig.3
Fig 2
Fig.1.
Fig.4
Witnesses
Inventor

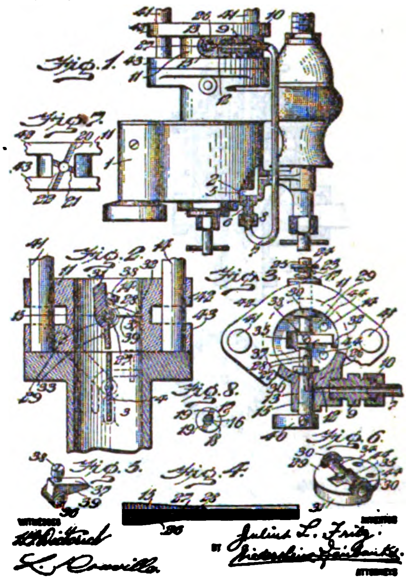
C. SMITH.
CARBURETER.
APPLICATION FILED NOV. 6, 1909.

995,919. Patented June 20, 1911.



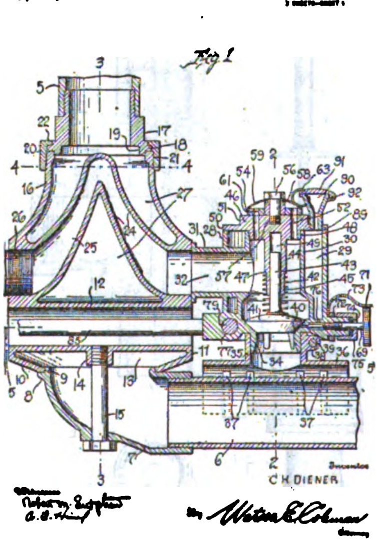
J. L. FRITZ.
PRIMING DEVICE FOR CARBURETERS.
APPLICATION FILED FEB. 16, 1912.

1,048,518. Patented Dec. 31, 1912.



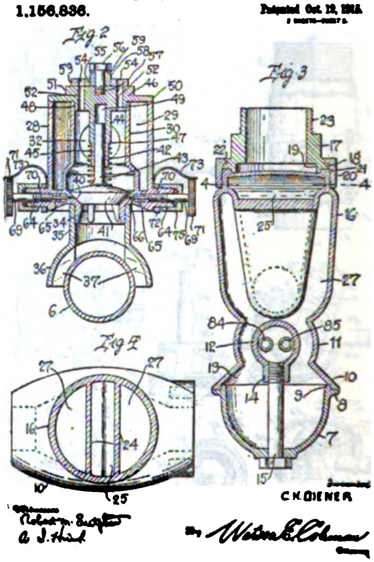
C. H. DIENER.
CARBURETER.
APPLICATION FILED OCT. 7, 1914.

1,156,836. Patented Oct. 12, 1915.
3 SHEETS—SHEET 1.



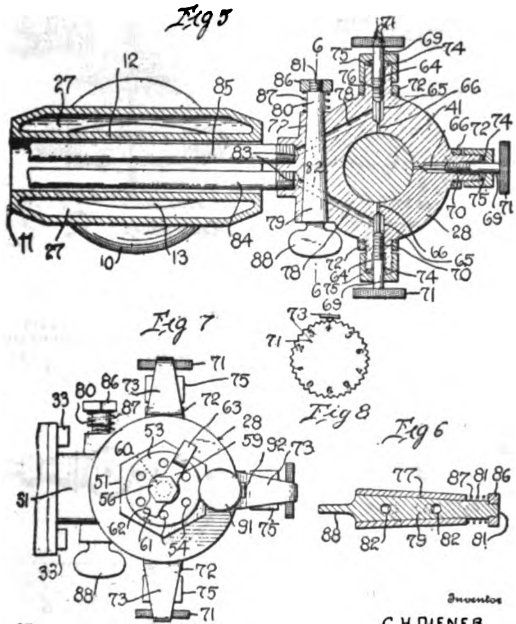
C. H. DIENER.
CARBURETER.
APPLICATION FILED OCT. 7, 1914.

1,156,836. Patented Oct. 12, 1915.
3 SHEETS—SHEET 2.



C. H. DIENER.
CARBURETER.
APPLICATION FILED OCT 1 1914.

1,156,836. Patented Oct. 12, 1915.
3 SHEETS—SHEET 3.



Inventor
C. H. DIENER

Witnesses
Robert M. Sutphen
A. I. Hurd

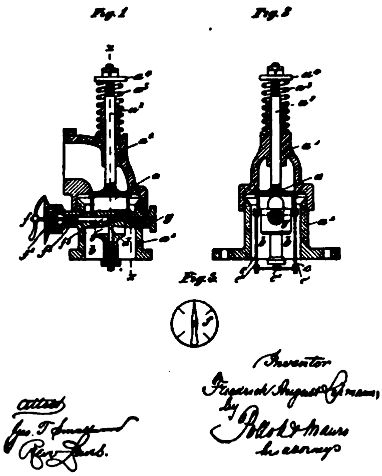
By Watson E. Coleman
Attorney

(No Model.)

F. A. LEHMANN.

MIXING VALVE FOR PETROLEUM OR OTHER MOTOR.

No. 500,401 Patented June 27, 1893.

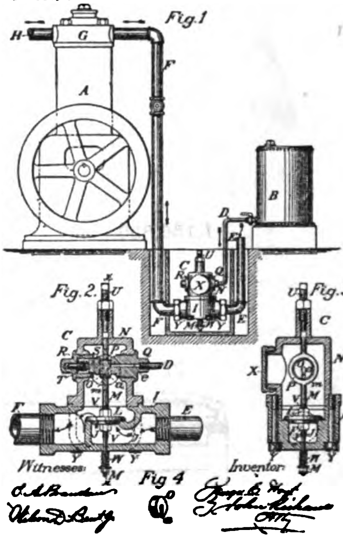


(No Model.)

G. E. HOYT

CARBURETING APPARATUS FOR GAS OR VAPOR ENGINES.

No. 515,660 Patented Feb. 20, 1894.

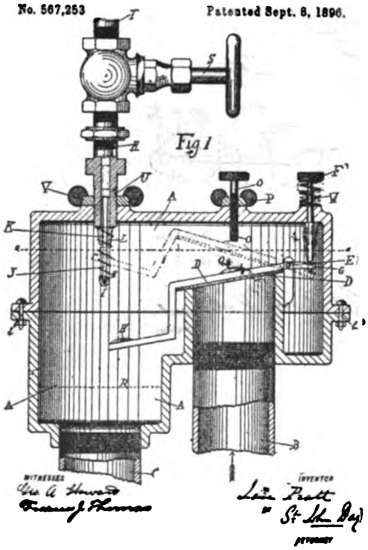


(No Model.) 2 Sheets—Sheet 1.

J. PRATT

VAPORIZER AND MIXER FOR GASOLENE ENGINES.

No. 567,253 Patented Sept. 8, 1896.

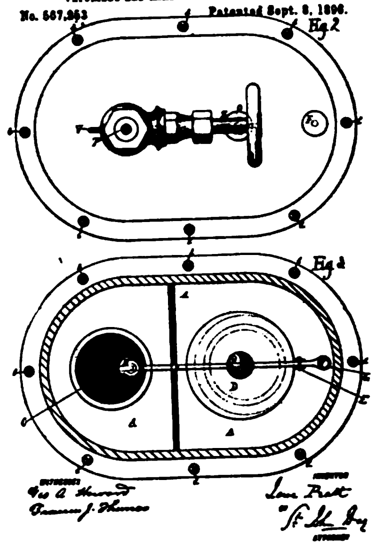


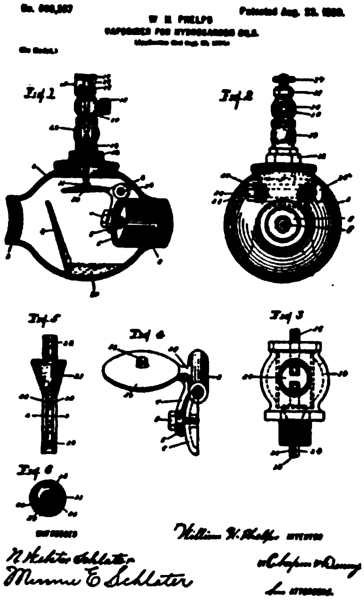
(No Model.) 2 Sheets—Sheet 2.

J. PRATT

VAPORIZER AND MIXER FOR GASOLENE ENGINES.

No. 567,253 Patented Sept. 8, 1896.





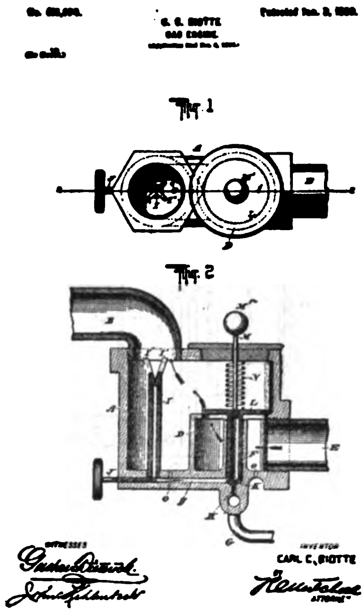


Fig. 1
Fig. 2
WITNESSES
INVENTOR
CARL C. RIOTTE

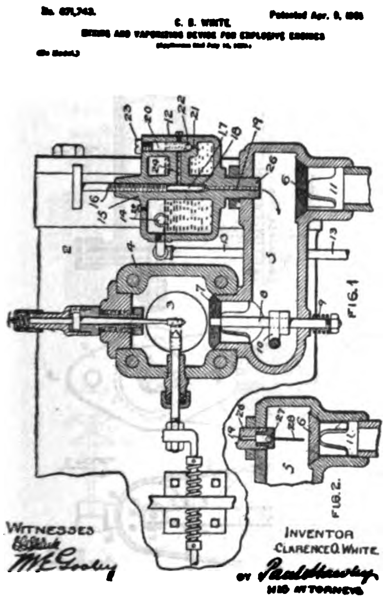


FIG. 1
FIG. 2
WITNESSES
INVENTOR
CLARENCE O. WHITE
HIS ATTORNEYS

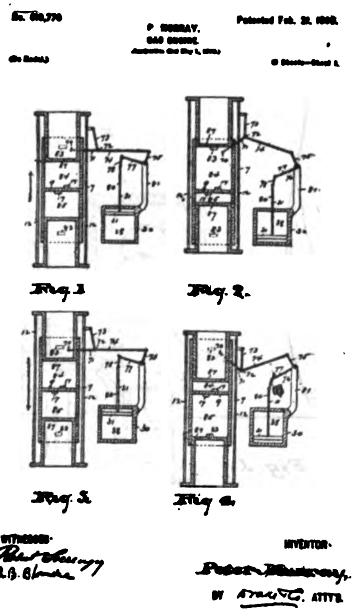
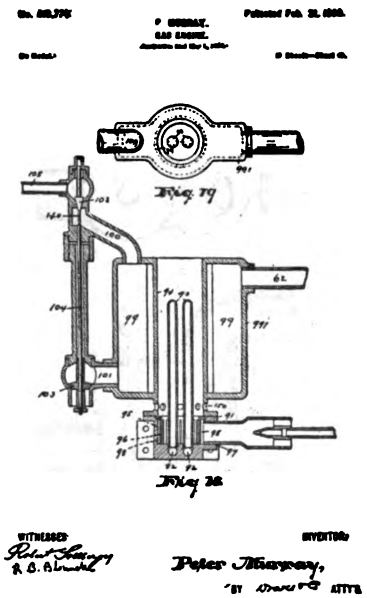
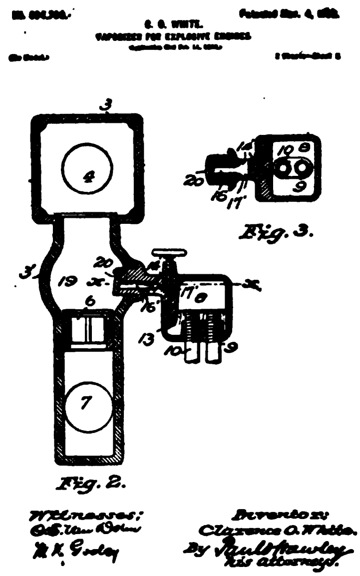
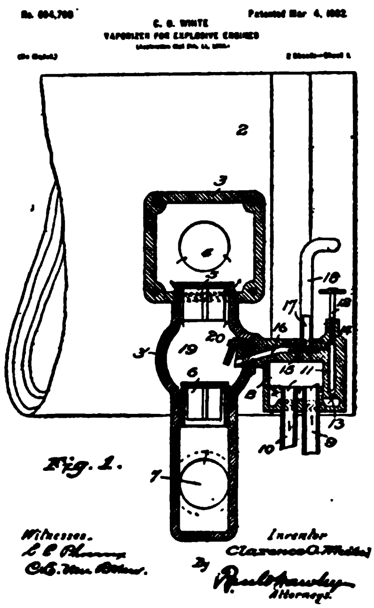
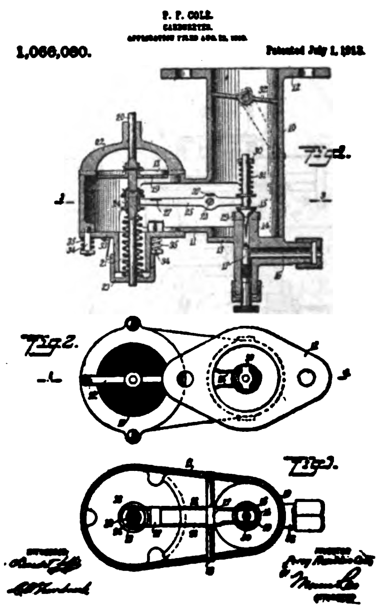


Fig. 1
Fig. 2
Fig. 3
WITNESSES
INVENTOR


Patented Feb. 21, 1899.
GAS ENGINE.
Fig. 19
Fig. 28
WITNESSES:
INVENTOR:
Peter Murray,
BY ATTYS


C. O. WHITE.
VAPORIZER FOR EXPLOSIVE ENGINES.
Fig. 3.
Fig. 2.
Witnesses:
Inventor:
Clarence O. White.
By Paul Hawley
his attorneys.


No. 694,708
Patented Mar. 4, 1902
C. O. WHITE
VAPORIZER FOR EXPLOSIVE ENGINES
Fig. 1.
Witnesses.
Inventor
Clarence O. White
By Paul Hawley
Attorneys.

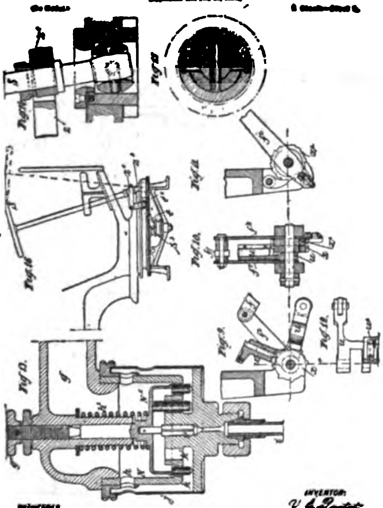

F. P. COLE.
CARBURETER.
1,066,080.
Patented July 1, 1913.
Fig. 1.
Fig. 2.
Fig. 3.

No. [illegible] V. E. PRÉTOT. Patented Sept. [illegible]

SELF PROPELLING CARRIAGE.

(Application filed [illegible])

(No Model.) [illegible] Sheets—Sheet [illegible]



INVENTOR: V. E. Prétot

WITNESSES:

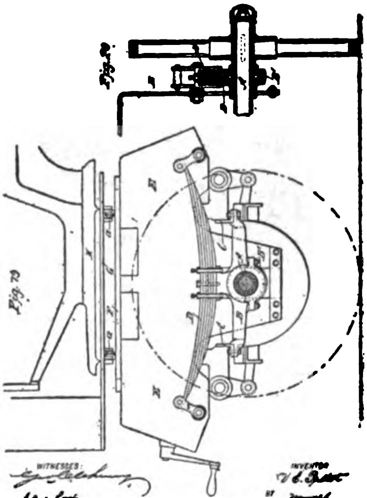
ATTORNEYS.

No. [illegible] V. E. PRÉTOT. Patented Sept. [illegible]

SELF PROPELLING CARRIAGE.

(Application filed [illegible])

(No Model.) [illegible] Sheets—Sheet [illegible]



WITNESSES:

INVENTOR: V. E. Prétot

ATTORNEYS.

No. [illegible] J. C. E. MATHIEU. Patented July [illegible]

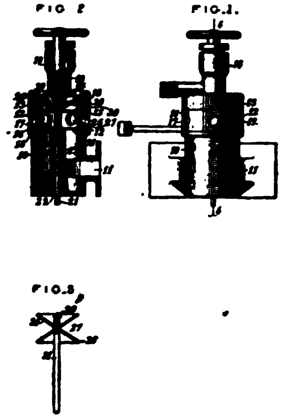
CARBURETING APPARATUS FOR EXPLOSION MOTORS.

(Application filed [illegible])

(No Model.)

FIG 2 FIG.1.

FIG.3



Witnesses

Inventor Joseph C. E. Mathieu

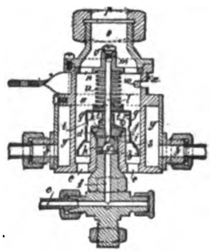
by [illegible] Attorney

No. [illegible] A. A. LONGUEMARE. Patented Dec. [illegible]

CARBURETER FOR EXPLOSIVE ENGINES.

(Application filed [illegible])

(No Model.)

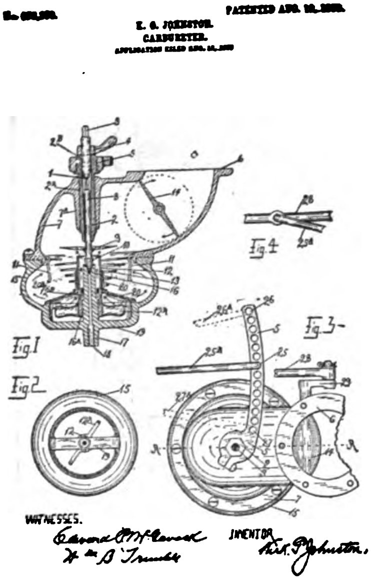


Witnesses

Inventor. Amélie Adèle Longuemare

by B. Singer

Atty.


CARBURETER.
Fig.1
Fig.2
Fig.3
Fig.4
WITNESSES.
INVENTOR

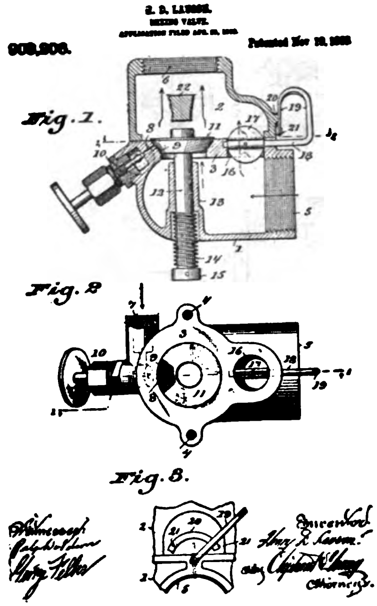
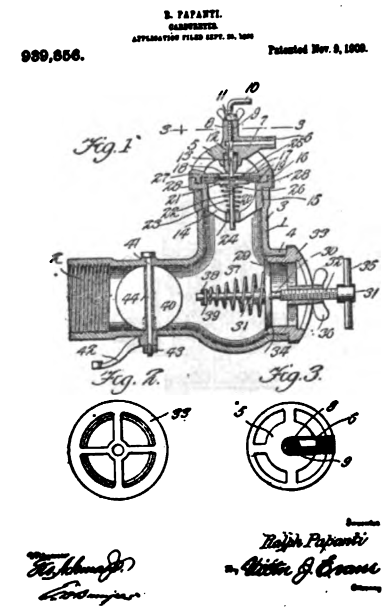
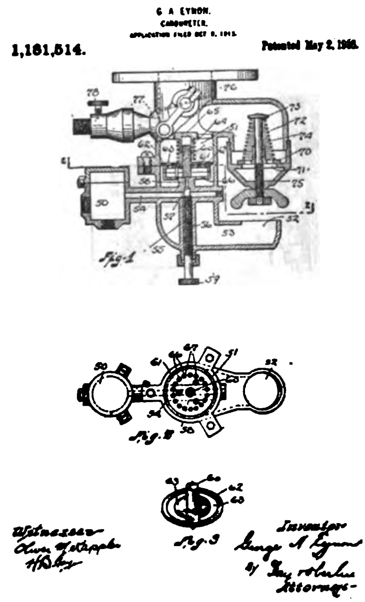


Fig.1.
Fig.2
Fig.3.


R. PAPANTI.
939,856.
Patented Nov. 9, 1909.
Fig.1
Fig.2.
Fig.3.
Ralph Papanti


G. A. EYRON.
CARBURETER.
1,181,514.
Patented May 2, 1916.
Fig.1
Fig.2
Fig.3
Witnesses
Inventor
Attorneys

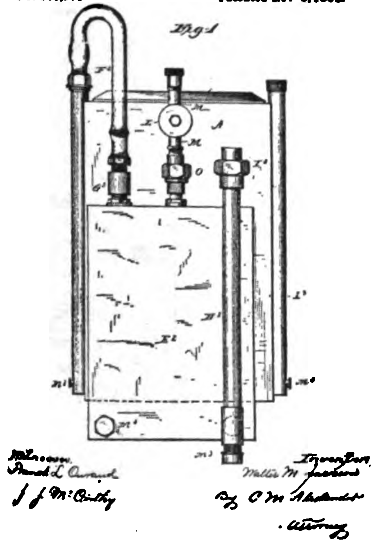
sequence the first of the proportioning-flow carburetors of the air-driven, fuel-volume meter type, shown on page 201. (249,363, Nov. 8, 1881, Jackson.) An ordinary gas meter acts as an air motor to drive a fuel meter consisting of a rotating plate with pockets on its face, the pockets filling as they pass a fuel chamber and emptying as they pass a port leading into the metered air stream. All the fuel is thus measured and proportioned to the air flowing with it as volumetrically proportioned mixture. The first case of this class designed directly for engine use where the bulk and cost of the old standard form of bellows gas meter would be prohibitive is that on page 201. (791,801, June 6, 1905, Leinau.) This has some of the characteristics of the aspirating jet type of structure. The float chamber, with its fuel passage and fuel outlet above the chamber level, are the same as would operate in the ordinary aspirating manner, except that the jet is located fairly high and in a region of low air velocity, as also is the air passage. There are added two new elements—first, a small centrifugal fuel pump in the fuel passage, and, second, an axial-flow fan-blade form of air motor in the path of the entering air, driving the pump. There is a suggestion, in view of the more or less frequent use of such fanlike motors as stirrers and mixers, that this is the primary idea here, though reliance is placed on the pump action to eject the fuel. The case is interesting rather for its suggestiveness than for its direct value, because the floow-speed pressure characteristic of the pump and air motor of these forms are not such as well maintain proportionality. Another form involving the same elements, but in which the centrifugal pump fuel passages discharge radially directly into the air instead of through a jet nozzle, as in the previous case, is shown on page 202. (957,976, May 17, 1910, Lucas.) A more directly proportioning arrangement based on volumetric displacements is that on page 202 (1,048,083, Dec. 24, 1912, Lavender), in which a rotary volume meter of the form common in the measurement of water is used as air motor and drives a pair of plunger fuel pumps. If the slip of these two displacers were exactly the same, and if there were no density variation in the air to cause variations in the weight of air, even when its volume is correctly proportioned to the fuel, this arrangement would seem to offer good prospects, at least as good as most of the direct-jet aspirators, as a proportioner. Of course there will be some unfavorable inertia lag elements to interfere with prompt acceleration of a variable-speed engine, and once it is operating at high speed the inertia of the moving parts of the proportioner will continue fuel delivery after the throttle is closed. Furthermore, the size of the apparatus must necessarily be large, as the speed of a gasoline pump can not be high, but the arrangement is truly one of the proportional-flow class.

A similar rotary meter type of air motor driving a gear form of fuel pump by friction disks to secure a suitable ratio for adjustment of proportions is shown on pages 202 and 203. (1,119,479, Dec. 1, 1914, Veeder.) There is also added a diaphragm form of fuel needle control to adjust the inlet automatically with change of speed, so as to keep the pump delivery pressure nearly constant. A late form of the centrifugal fuel pump driven by an air motor of the turbine class is shown on page 203 (1,137,238, Apr. 27, 1915, Sherman), the rotor

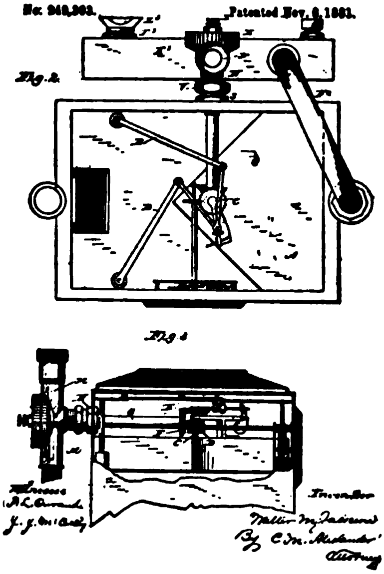
being mounted on ball bearings directly above the float chamber and the pump consisting primarily of a curved disk concave upward with an orifice restricted entrance. Still a different form involving an impulse form of air motor is shown on page 203 (1,149,323, Aug. 10, 1915, Baker & Swan), where an automatic intake valve of the swing-check type is employed as an air-entrance nozzle to direct the air to the motor vanes at approximately constant velocity as the intake gate varies. A gear type of fuel pump delivers the air to the throat of an air-delivery venturi tube for spraying where, of course, there will be a depression of pressure, helping to induce fuel flow. Some air at high speed by-passes the spraying tube through swing checks, tending to keep the delivery velocity through the spraying throat approximately constant.

Class 3, carburetors, proportioning flow, aspirating, single-fixed fuel and air inlets.—Nothing simpler than this structural arrangement for a proportioning flow carburetor could well be conceived, so it is quite natural to find many efforts to devise arrangements which by reason of their details or dimensions might be made to work satisfactorily enough for at least some sorts and sizes of engines. One of the early cases, page 204 (622,274, Sept. 19, 1899, Riotte), has a constant level chamber of the overflow type and a fuel passage branching beyond the needle valve to four orifices for mixing purposes, the whole chamber being doubled for direct bolting to the two intake ports of a two-cylinder stationary engine. A different form of constant-level cup of overflow type is shown on page 204 (658,267, Sept. 18, 1900, Kennedy), constructed somewhat like a plumbing trap, and still another form on page 205 (682,596, Sept. 17, 1901, Aldrich), which has in addition a plug form of fuel adjusting valve. Location of the fuel nozzle in the center of a float type of constant-level chamber to keep the fuel head constant in spite of the titling that is a necessary part of transportation service is shown on pages 205 and 206 (685,993, Nov. 5, 1901, Le Blon), in which the nozzle is axially situated in a straight portion of a cylindrical air passage, air and fuel flowing in the same direction, the air passage being provided with a manually adjusted restricted inlet. Cross flow is illustrated on page 206 (724,648, Apr. 7, 1903, Zimmermann), the fuel needle valve stem crossing a straight air passage at right angles and being carried in a cage that restricts air flow. Another such crossing fuel valve stem is shown on page 206 (729,647, May 26, 1903, White), arranged, however, in a bend, so the air passes the fuel inlet at an angle and, by reason of the obstructions, with many eddy currents. Location of a fuel heater between the fuel-measuring nozzle and the point of mixture with the air at which the fuel flow-inducing vacuum originates is illustrated on page 206. (804,589, Nov. 14, 1905, Enrico.) This fuel nozzle, of the multiple-outlet form, discharges over a series of heated tubes, where its fuel is to be vaporized in its own atmosphere. Of course the heating develops some expansion, which has a similar influence to flow resistance, and if the heat were variable there would be a variation of proportions due to it alone, independent of other influences. A curious form of fuel passage, made crooked for the purpose of resisting excessive increases of fuel flow, is shown on page 207. (846,903, Mar. 12, 1907, Bradbeer.) On page 207 (936,337, Oct. 12, 1904, Maybach) is

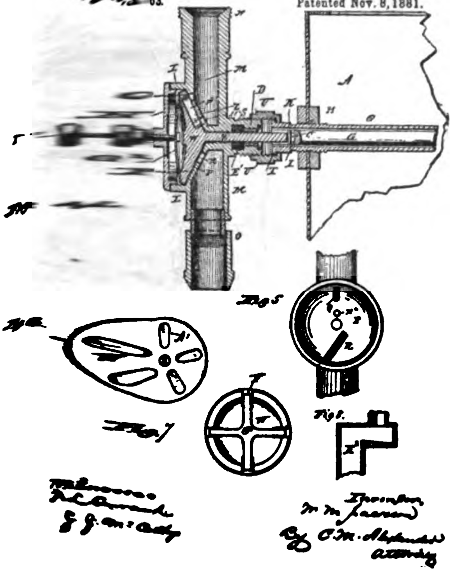
W. M. JACKSON.
METRICAL CARBURETOR.
No. 249,263. Patented Nov. 8, 1881.
3 Sheets—Sheet 1.



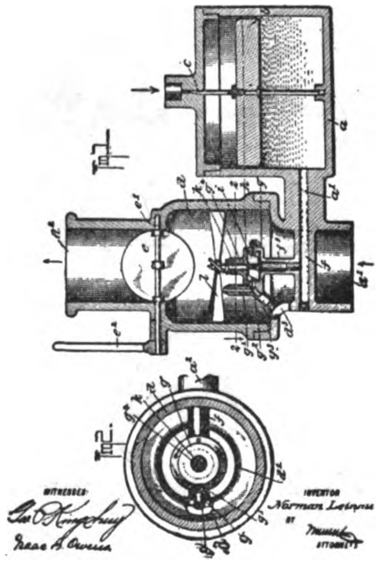
W. M. JACKSON.
METRICAL CARBURETOR.
No. 249,263. Patented Nov. 8, 1881.
3 Sheets—Sheet 2.



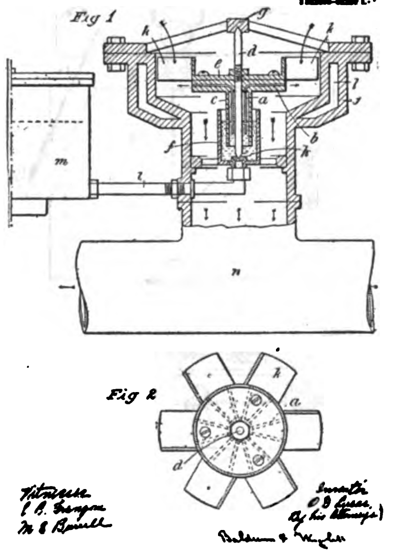
W. M. JACKSON.
METRICAL CARBURETOR.
No. 249,263. Patented Nov. 8, 1881.
3 Sheets—Sheet 3.



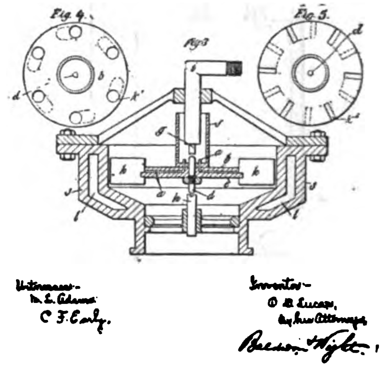
No. 791,801. PATENTED JUNE 6, 1905.
N. LEINAU.
CARBURETER FOR HYDROCARBON ENGINES.
APPLICATION FILED JULY 21, 1904.



957,976. Patented May 17, 1910.

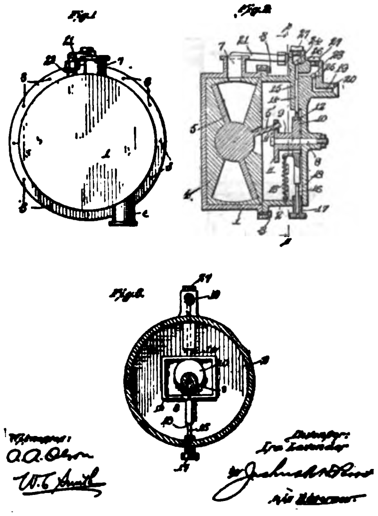


957,976. Patented May 17, 1910.



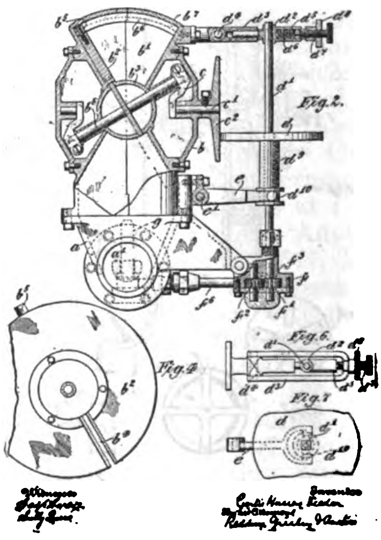
I. LAVENDER.
CARBURETING DEVICE.

1,048,063. Patented Dec. 24, 1912.



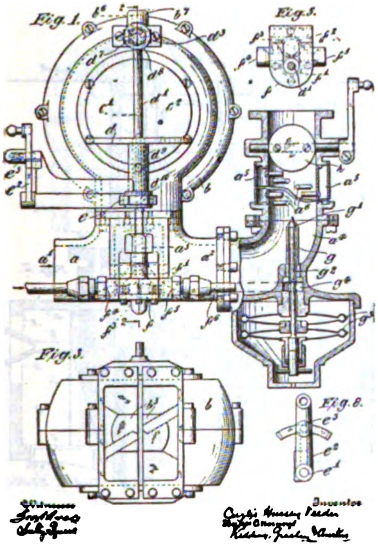
C. H. VEEDER.
CARBURETER.

1,119,479. Patented Dec. 1, 1914.



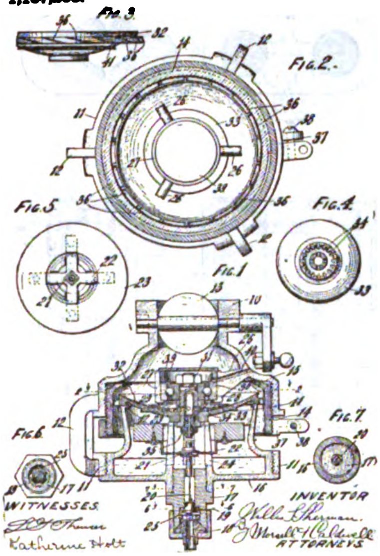
C. R. VEEDER.
CARBURETER.

1,119,479. Patented Dec. 1, 1914.



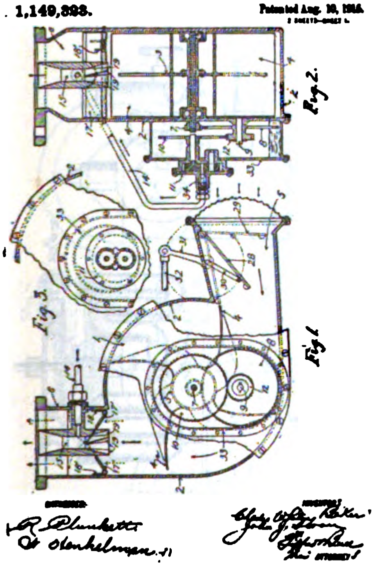
W. S. SHERMAN.
CARBURETER.

1,137,268. Patented Apr. 27, 1915.



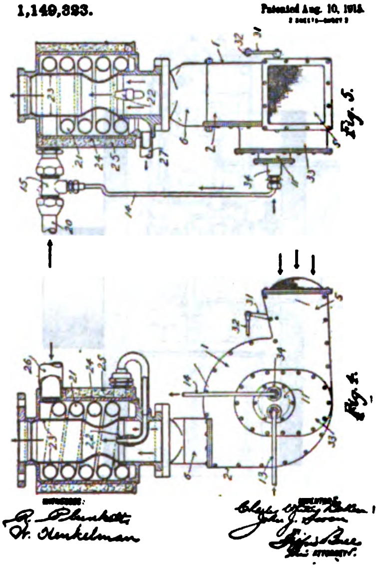
C. W. BAKER & J. J. SWAN.
APPARATUS FOR FEEDING FUEL TO OIL ENGINES.

1,149,323. Patented Aug. 10, 1915.



C. W. BAKER & J. J. SWAN.
APPARATUS FOR FEEDING FUEL TO OIL ENGINES.

1,149,323. Patented Aug. 10, 1915.



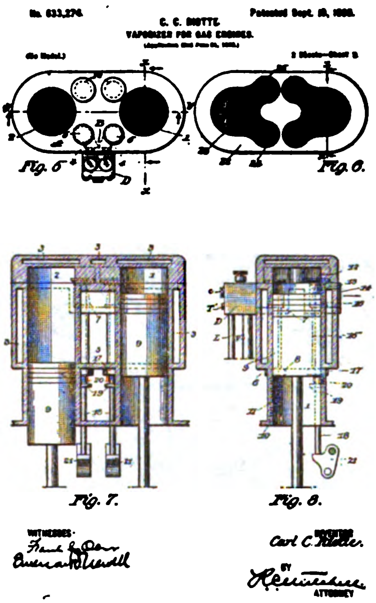


Fig. 5.
Fig. 6.
Fig. 7.
Fig. 8.
WITNESSES:
INVENTOR
Carl C. Riotte.
BY
ATTORNEY

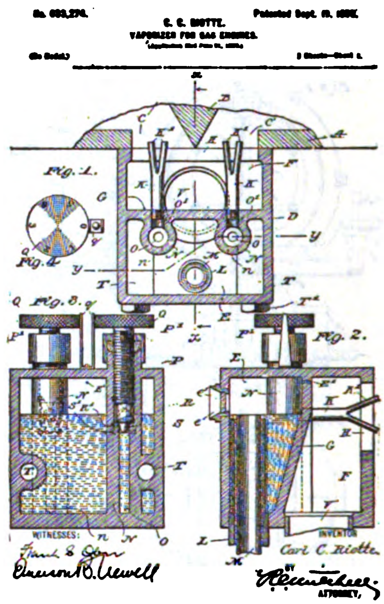


Fig. 1.
Fig. 4.
Fig. 3.
Fig. 2.
WITNESSES:
INVENTOR
Carl C. Riotte.
BY
ATTORNEY,

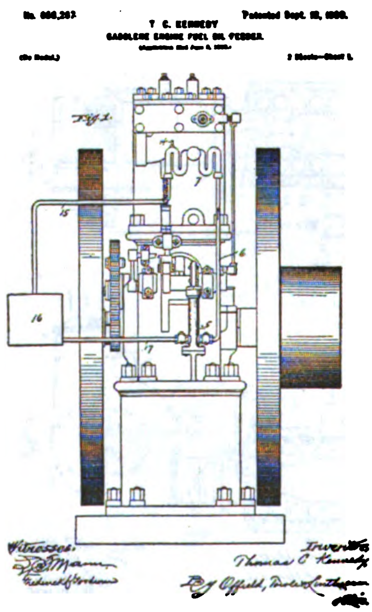


Fig. 1.
Witnesses:
Inventor
Thomas C. Kennedy

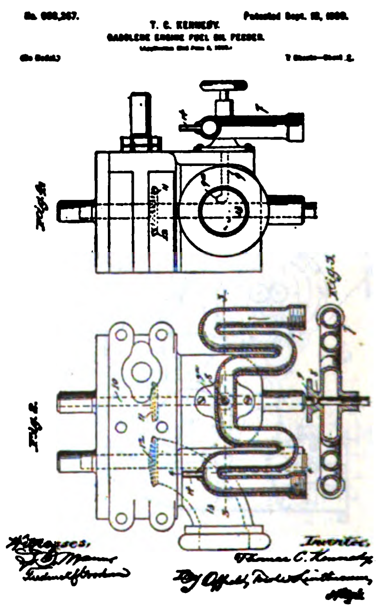


Fig. 2.
Fig. 3.
Witnesses:
Inventor,
Thomas C. Kennedy

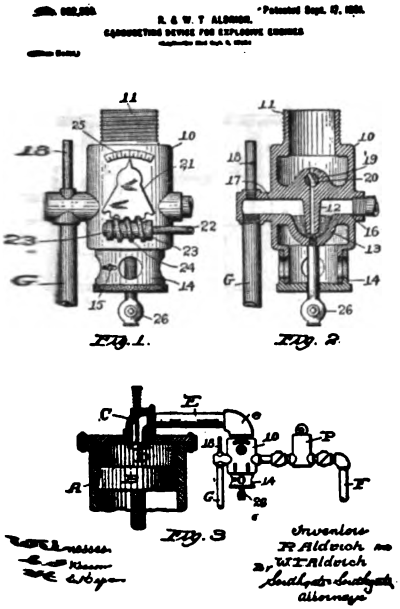
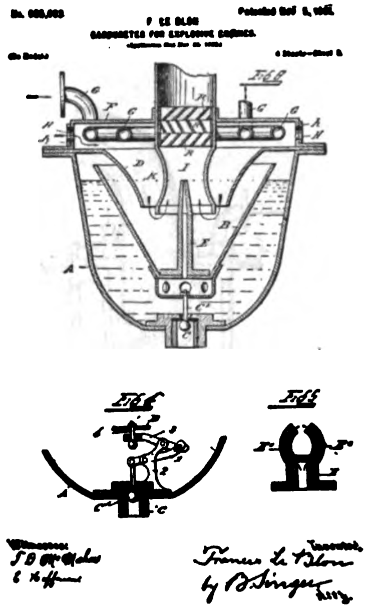
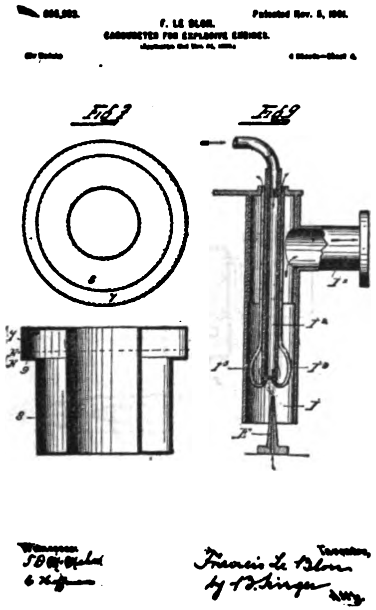
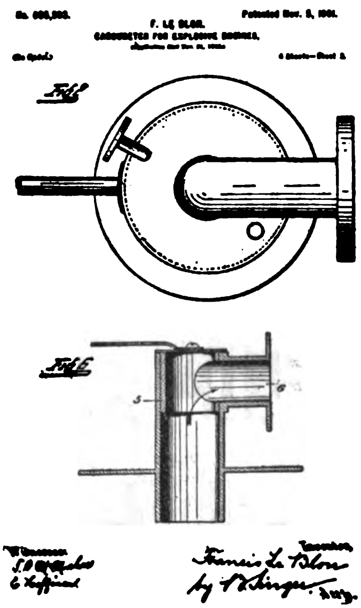


Fig. 1.
Fig. 2.
Fig. 3
Inventors
R Aldrich
W T Aldrich


Francis Le Blon
by B. Singer Atty.


Francis Le Blon
by B. Singer Atty.


Francis Le Blon
by B. Singer Atty.

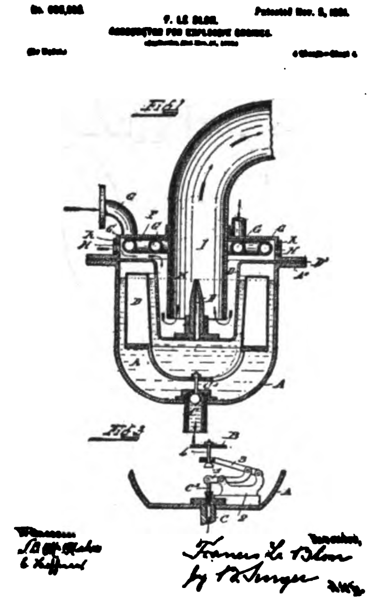
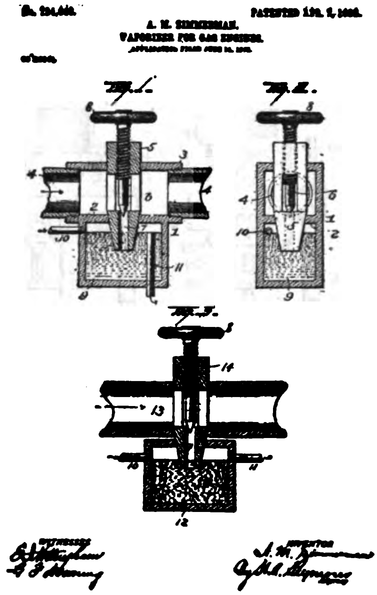
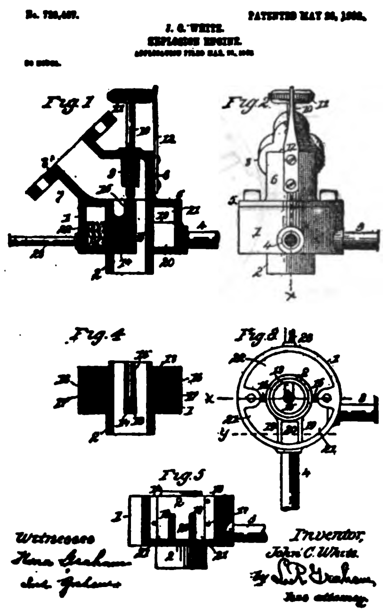
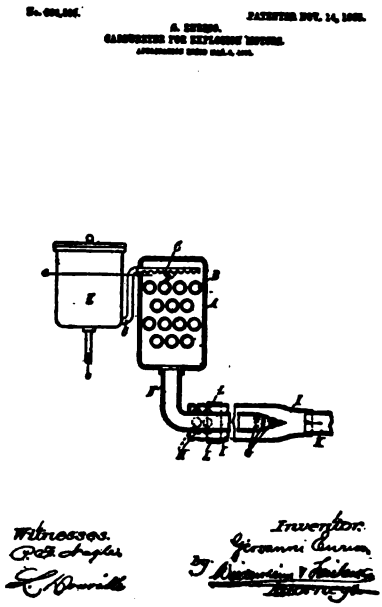


Fig. 1
Fig. 3
Francis L. Bloa


A. M. ZIMMERMAN.
VAPORIZER FOR GAS ENGINES.


PATENTED MAY 26, 1903.
J. C. WHITE.
EXPLOSION ENGINE.
Fig. 1
Fig. 2
Fig. 4
Fig. 3
Fig. 5
Witnesses
Inventor,
John C. White.
his attorney

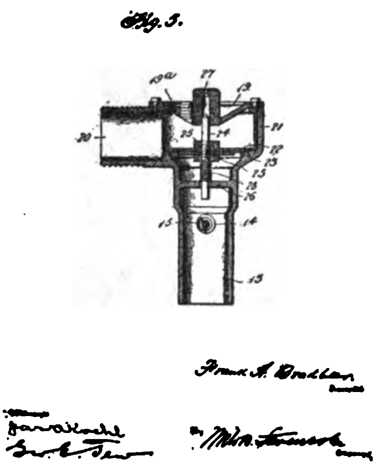

Witnesses.
Inventor.
Giovanni Enrico

PATENTED MAR. 12, 1909.

F. A. BRADBEER,

CARBURETER.

APPLICATION FILED JAN. 14, 1908.

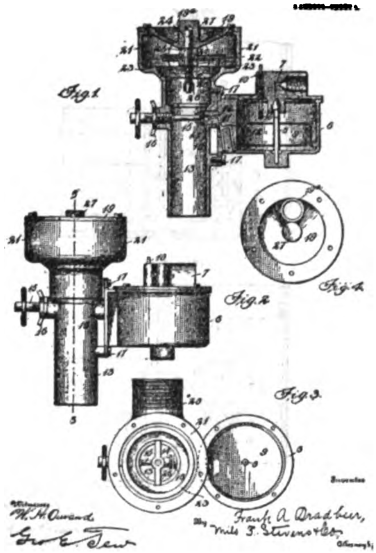


PATENTED MAR. 12, 1909.

F. A. BRADBEER.

CARBURETER.

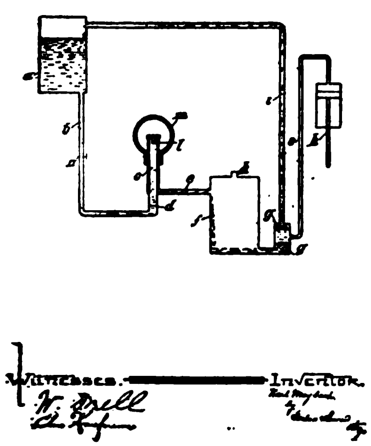
APPLICATION FILED JAN. 14, 1908.



K. MAYBACH.

CARBURETER.

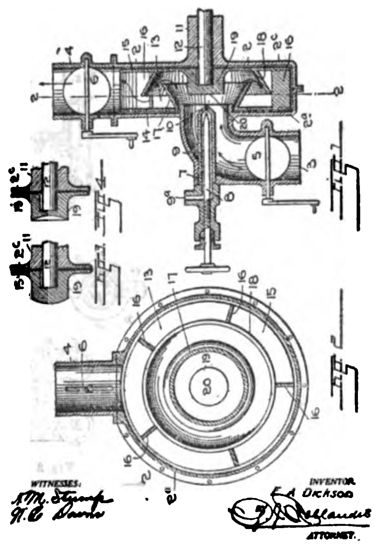
936,337. Patented Oct. 12, 1909.



E. A. DICKSON.

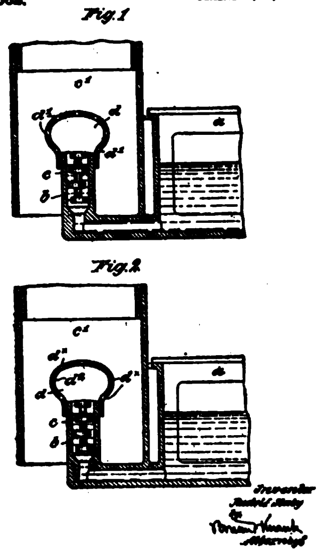
CARBURETER.

939,481. Patented Nov. 9, 1909.



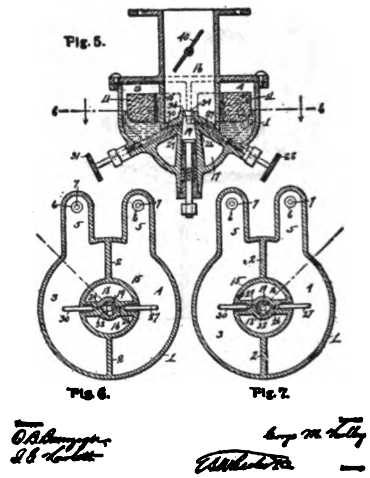
R. SLABY.
CARBURETOR.

1,160,669. Patented Nov. 16, 1915.



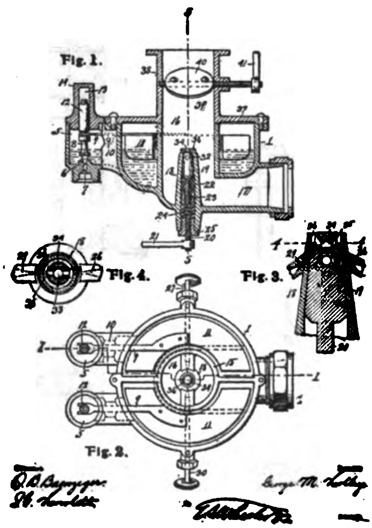
G. M. HOLLEY.
CARBURETOR.

1,171,200. Patented Feb. 8, 1916.



G. M. HOLLEY.
CARBURETOR.

1,171,200. Patented Feb. 8, 1916.



another scheme for modifying fuel exit by causing a continuous circulation of fuel through the fuel nozzle in the direction of the fuel exit, the overflow chamber being incorporated in the nozzle, so there is always some velocity head of fuel, contributing to the fuel flow, in addition to the air-flow vacuum.

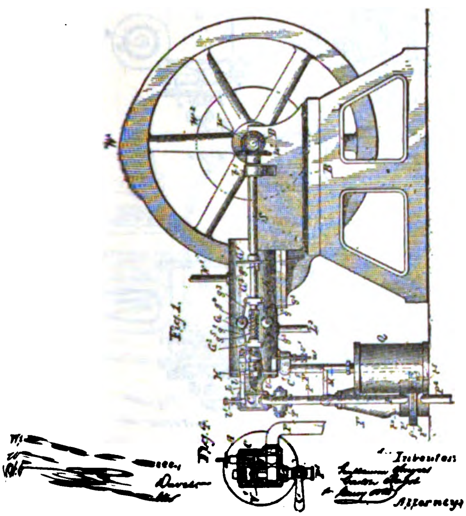
In all the cases so far the vacuum at the fuel inlet is due mainly or exclusively to an entrance resistance and flow resistance up to the fuel nozzle and not to any particular velocity head conditions, due to contractions of passage or to bends and baffles. On page 207 (939,481, Nov. 9, 1909, Dickson) the fuel nozzle is located in a curved elbow and the air will tend to crowd away from the jet more in proportion as its velocity is higher, so that the vacuum due to air velocity, independent of entrance resistance, will not increase at the fuel inlet as fast as the air flow itself does. This is a sort of corrector for the tendency toward excess recliners or increased flow. An indication of the recent, though as yet feeble, tendency to study the flow laws of passages of different forms and to develop flow passages that have suitable flow laws that contribute to proportionality is the peculiar fuel passage and nozzle on page 208. (1,160,662, Nov. 16, 1915, Slaby.) The perforated rose head may be so formed as to give quite a range of control of liquid flow vacuum at the top of the vertical tube, by location and size of the holes, and the baffles in the fuel passage may likewise serve as a means of control of the fuel flow law with reference to the effective vacuum, of course, each within suitable limits. Two fuels, each with its own float chamber and adjustably fixed fuel passage, discharge alternately to the same fuel nozzle by the turning of a central switch valve in the form on page 208 (1,171,200, Feb. 8, 1916, Holley) intended for engines starting on gasoline and later operated when hot on kerosene.

Subclass 3.1—Fuel inlet at air throat.—Contraction of the air passage walls in the manner used in injectors and compressed air spray nozzles but applied to aspirating flow is illustrated on page 211. (350,769, Oct. 12, 1886, Ragot & Smyers.) As here applied it delivers the mixture in whatever proportions the form and dimensions make possible to a heated pot for vaporization, so that the engine may operate as an oil engine on heavy fuel. This is another one of that class of oil engines developed from the gasoline engine by the addition to the latter of a mixture heater. Placing the fuel inlet at a restriction in the air passage or air throat or choke tube makes fuel flow primarily dependent on the air velocity head rather than entrance restriction, as illustrated on pages 211 and 212 (693773, Feb. 18, 1902, Bardwell), an axial parallel flow arrangement, and on page 212 (789,537, May 8, 1905, Growville & Arguembourg) a cross-flow arrangement, but without a fuel valve stem crossing the air passage. Such a throat arrangement of curved form where the fuel valves do cross is shown on page 212 (906,980, Dec. 15, 1908, Winton & Anderson), in which the air tends to beat against the fuel inlet, restricting its flow as the air velocity increases more than if the flow were parallel or than for plain cross flow, thereby tending to correct their fuel flow excesses at high rates. As the fuel inlet is submerged a pool will form, which on a sudden increase of air flow will be picked up and carried along aiding acceleration, so this is one form of

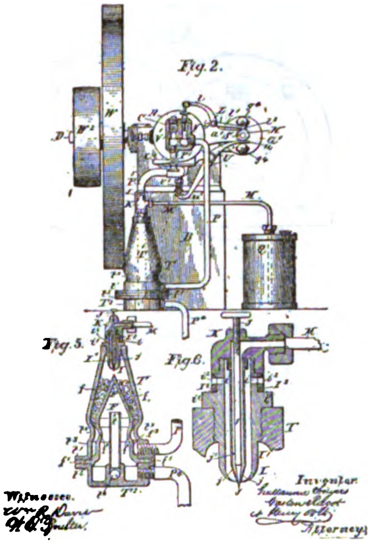
accelerating cup. A rather good form of air passage, practically a venturi tube, by reason of the small angle of the discharge cone, and having parallel axial flow, as shown on page 213 (954,905, Apr. 12, 1910, Wolf), which is also provided with a heating jacket between the float chamber and throat to promote vaporization. Heaters located like this will affect the densities of the fuel and air, and the viscosity of the former, and therefore change their proportionality accordingly. To secure an initial flow inducing vacuum of a given fixed minimum value, from which the vacuum may begin to rise instead of starting with zero with reference to flow rate, a light gravity loaded check valve striking a stop is used on page 213. (1,038,699, Sept. 12, 1912, Wilkinson.) This is of special service at low-rate flow or on idling, but in no other way does it change the proportionality characteristics of the other arrangements from what they would be with a fixed air inlet of area equal to that available with the air check valve open. Adaptation of the contracted throat means of developing a localized vacuum to induce fuel flow to the closed crank case form of two-cycle engine is illustrated on pages 213 and 214 (1,117,641, Nov. 17, 1914, Cottle), where the fuel inlet is at the throat and the upstream wide end of the conical air passage is connected to the top of the float chamber. In this way the fact that the air is under a pressure greater than atmosphere makes no difference in the flow proportionality. It is a good illustration of the fact that float chamber surface pressure equalization with the air supply passage adapts practically any carburetor to the use of compressed air, even though it were designed for pure aspiration from the free atmosphere. The curved air throat with cross fuel discharge and accelerating cup is illustrated again on page 214 (1,130,981, Mar. 9, 1915, Kingston), but with an additional element, a low speed lifting tube for wet mixture. Around the steam of the fuel adjusting valve a loose sleeve is placed, passing through the dividing wall, and through which the fuel and air will be lifted at low-flow rates by the head equivalent to the check ball. The lifting will be assured at rates so low as would fail to lift the fuel in an ordinary passage if, as is the case with most of the present day gasoline, it resists prompt vaporization. An interesting form of lifting tube passing directly through the center of a damper throttle is illustrated on page 214 (1,190,714, July 11, 1916, Bottome), here applied to a simple venturi throat carburetor of noncompensating form, but evidently applicable to others.

Subclass 32—Air guides or baffles.—The object of such baffles or air guides is to correct the tendency for fuel to increase faster than or just to mix the two. Arrangement of the air passage in the form of a return bend with a small tube projection in each leg permits the air velocity head to act positively at one and negatively on the other, and connection of one above and the other below the fuel surface in the closed constant-level chamber gives practically twice the flow-inducing pressure difference that is normally used. This is illustrated on page 215. (660,482, Oct. 23, 1900, Bates.) Mixing is the object of the helical baffle on page 216. (737,463, Aug. 25, 1903, Pearson.) Formation of a spraying passage in the main air passage by baffles is illustrated on page 216. (791,501, June 6, 1905, Richard.) Flow correction, the former action, will undoubtedly take place in the form,

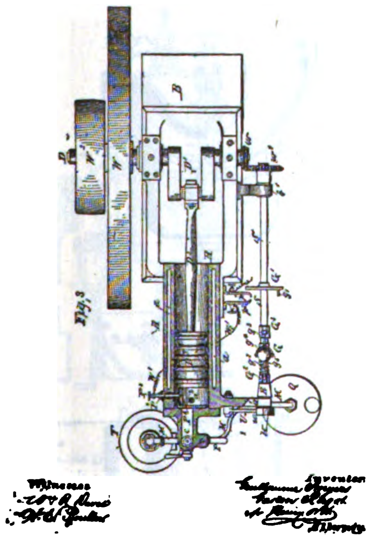
(No Model.) G. BAGOT & G. SMYERS. 3 Sheets—Sheet 1.
PETROLEUM AND GAS MOTOR.
No. 350,769. Patented Oct. 12, 1886.



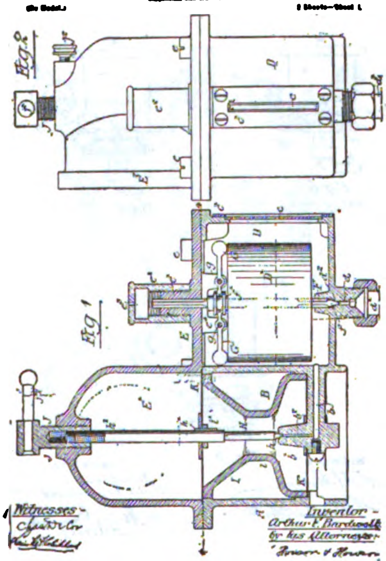
(No Model.) G. BAGOT & G. SMYERS. 3 Sheets—Sheet 2.
PETROLEUM AND GAS MOTOR.
No. 350,769. Patented Oct. 12, 1886.



(No Model.) G. BAGOT & G. SMYERS. 3 Sheets—Sheet 3.
PETROLEUM AND GAS MOTOR.
No. 350,769. Patented Oct. 12, 1886.



No. 693,773. Patented Feb. 18, 1902.
A. F. BARDWELL.
CARBURETER FOR EXPLOSIVE ENGINES.
(No Model.) 2 Sheets—Sheet 1.



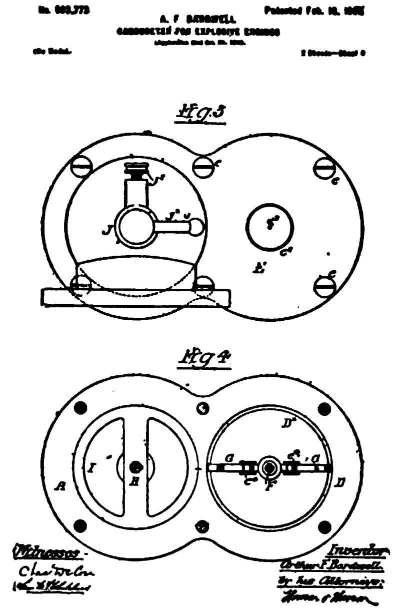
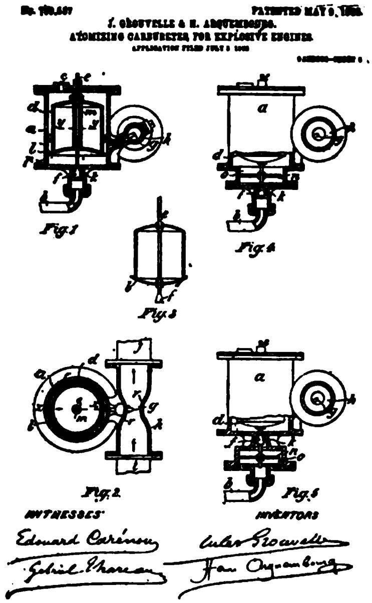
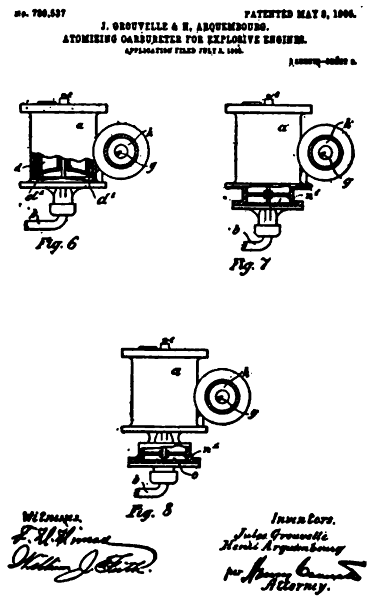
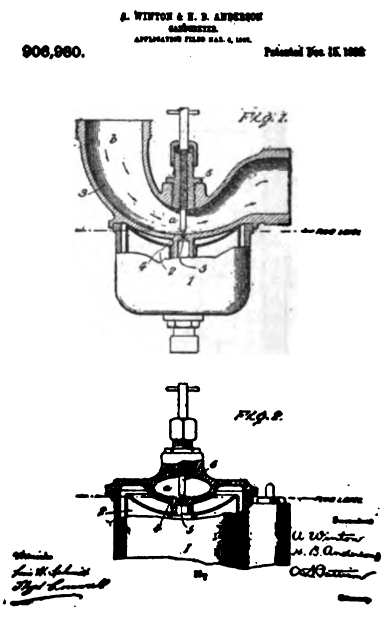


Fig. 3
Fig. 4
Witnesses
Inventor
By his Attorneys

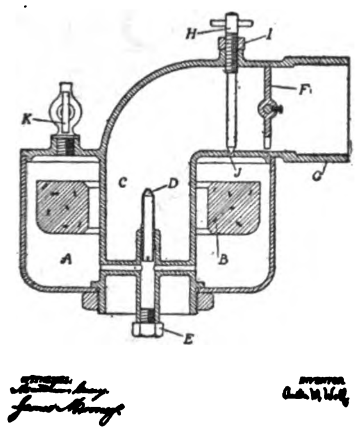

J. GROUVELLE & H. ARQUEMBOURG.
ATOMIZING CARBURETER FOR EXPLOSIVE ENGINES.
Fig. 1
Fig. 3
Fig. 4
Fig. 2
Fig. 5
WITNESSES
INVENTORS


J. GROUVELLE & H. ARQUEMBOURG.
ATOMIZING CARBURETER FOR EXPLOSIVE ENGINES.
Fig. 6
Fig. 7
Fig. 8
Witnesses.
Inventors.
Jules Grouvelle
Henri Arquembourg
per
Attorney.


A. WINTON & H. B. ANDERSON
CARBURETER.
906,960.
FIG. 1.
FIG. 2.

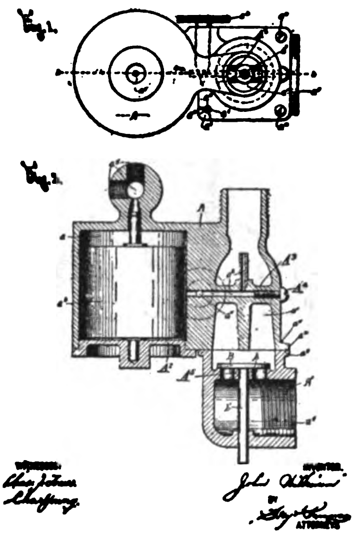
A. M. WOLF.
CARBURETER.
APPLICATION FILED MAY [illegible]

954,498. Patented Apr. 12, 1910.



J. WILKINSON.
CARBURETER.
APPLICATION FILED AUG. [illegible]

1,038,609. Patented Sept. 17, 1912.



A. P. COTTLE.
INTERNAL COMBUSTION ENGINE.
APPLICATION FILED MAY [illegible] 1914.

1,117,641. Patented Nov. 17, 1914.
2 SHEETS—SHEET 1.

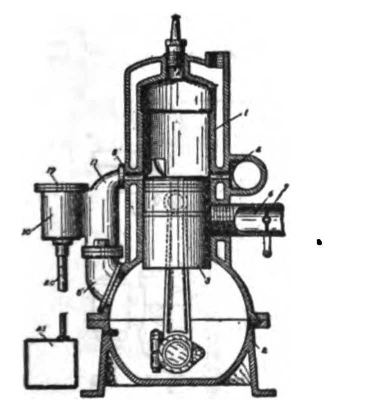


FIG. I.

Arthur P. Cottle

A. P. COTTLE.
INTERNAL COMBUSTION ENGINE.
APPLICATION FILED MAY [illegible] 1914.

1,117,641. Patented Nov. 17, 1914.
2 SHEETS—SHEET 2.

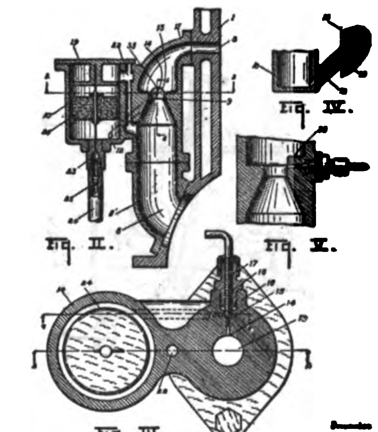


FIG. III.

Arthur P. Cottle

A. P. COTTLE.
INTERNAL COMBUSTION ENGINE.
APPLICATION FILED MAY [illegible], 1914.

1,117,641. Patented Nov. 17, 1914.

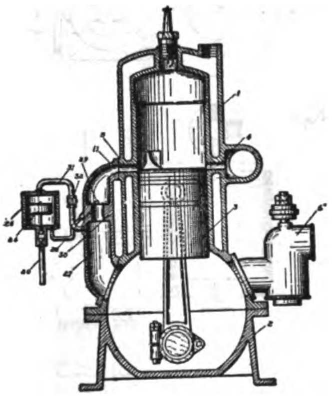


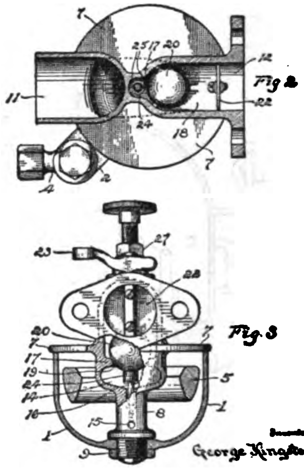
FIG. VI.

Inventor
Arthur P. Cottle
By Chappell & Earl
Attorneys

Witnesses
[illegible]

G. KINGSTON.
CARBURETER.
APPLICATION FILED OCT. [illegible]

1,180,981. Patented Mar. [illegible]



Inventor
George Kingston
By [illegible]
Attorneys

Witnesses
[illegible]

G. KINGSTON.
CARBURETER.
APPLICATION FILED OCT. [illegible]

1,180,981. Patented Mar. [illegible]

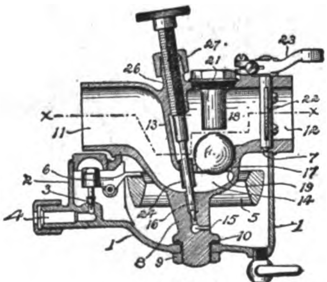


Fig. 1.

Inventor
George Kingston
By [illegible]
Attorneys

Witnesses
[illegible]

T. D. BOTTOME.
METHOD OF AND APPARATUS FOR CARBURETING.
APPLICATION FILED JULY [illegible]

1,190,714. Patented July [illegible]

Fig. 1.

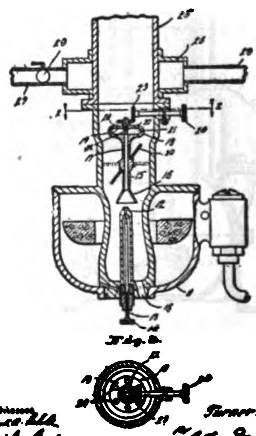
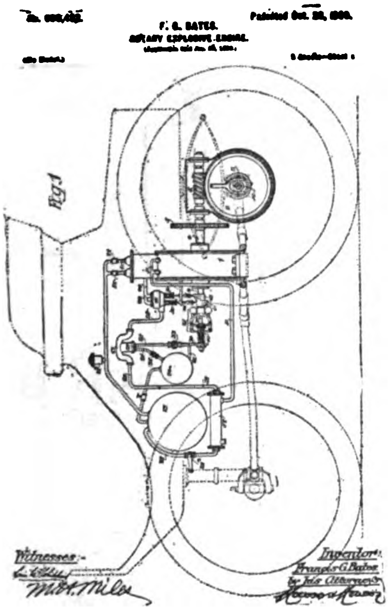
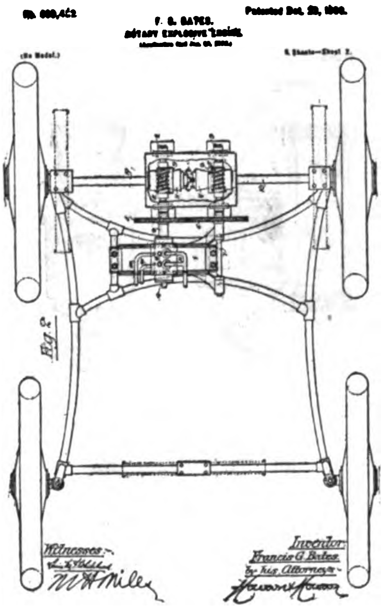


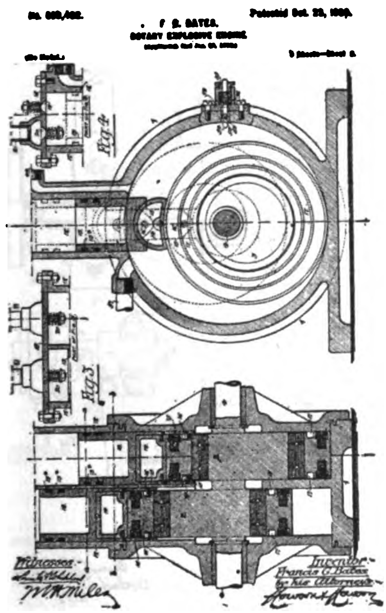
Fig. 2.

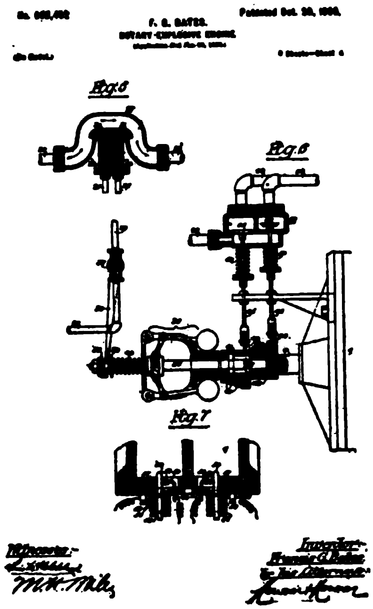
Inventor
Turner D. Bottome,
By [illegible]
Attorney

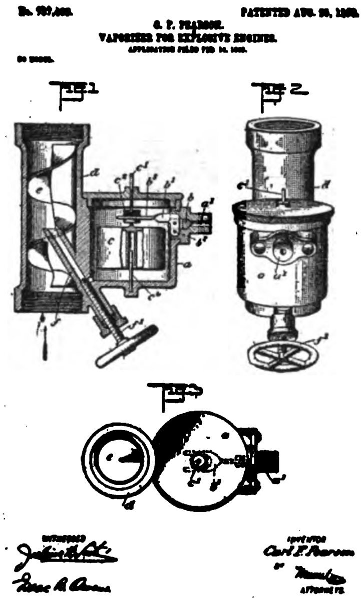
Witnesses
[illegible]

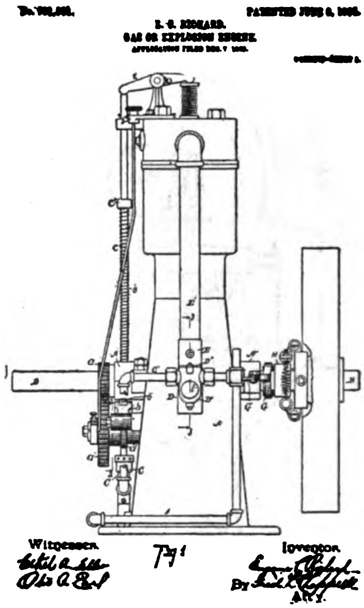

F. G. BATES.
Fig.1
Witnesses:
Inventor:
Francis G. Bates
by his Attorneys

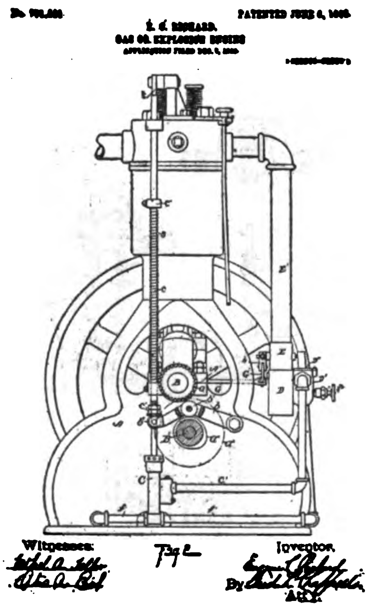

F. G. BATES.
Fig.2
Witnesses:
Inventor:
Francis G. Bates
by his Attorneys

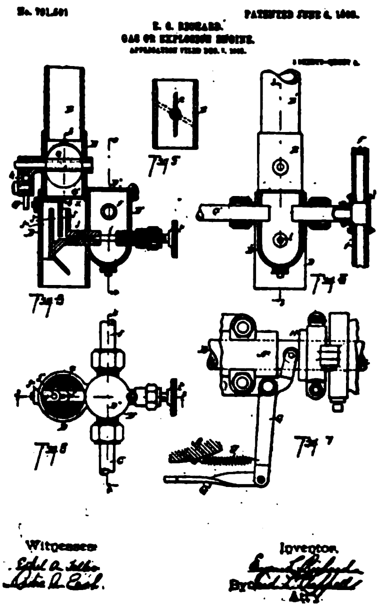

F. G. BATES.
Fig.4
Fig.3
Witnesses:
Inventor:
Francis G. Bates
by his Attorneys


F. G. BATES.
Fig.5
Fig.6
Fig.7
Witnesses:
Inventor:
Francis G. Bates
by his Attorneys




Witnesses.
Inventor.
By
Atty.


Witnesses.
Inventor.
By
Atty.


Witnesses.
Inventor.
By
Atty.

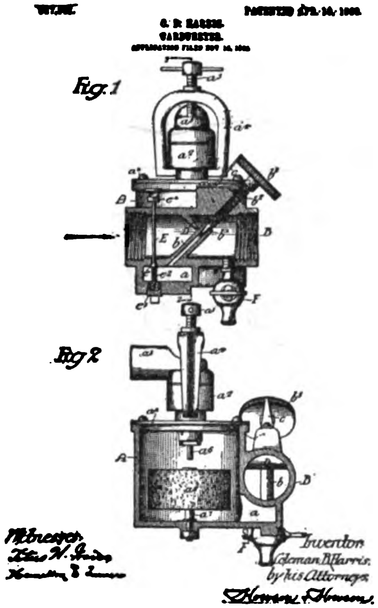


Fig. 1
Fig. 2
Inventor
Coleman B. Harris,
by his Attorneys

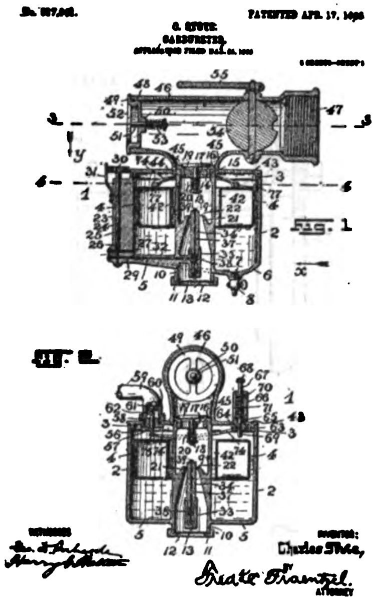


FIG. 1
FIG. 2
ATTORNEY

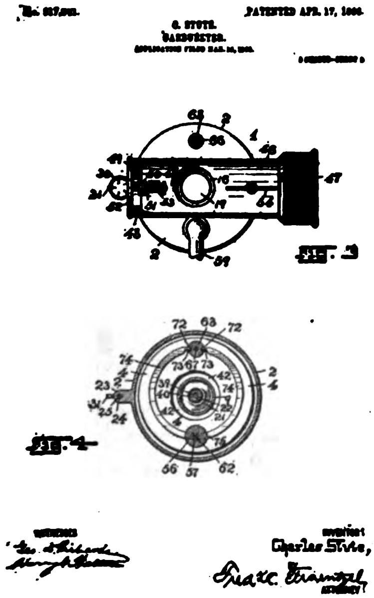


FIG. 3
FIG. 4

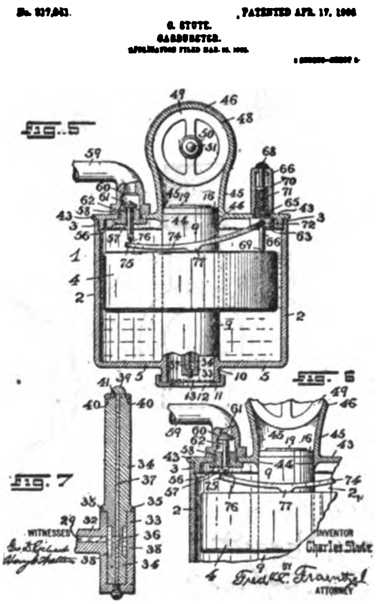


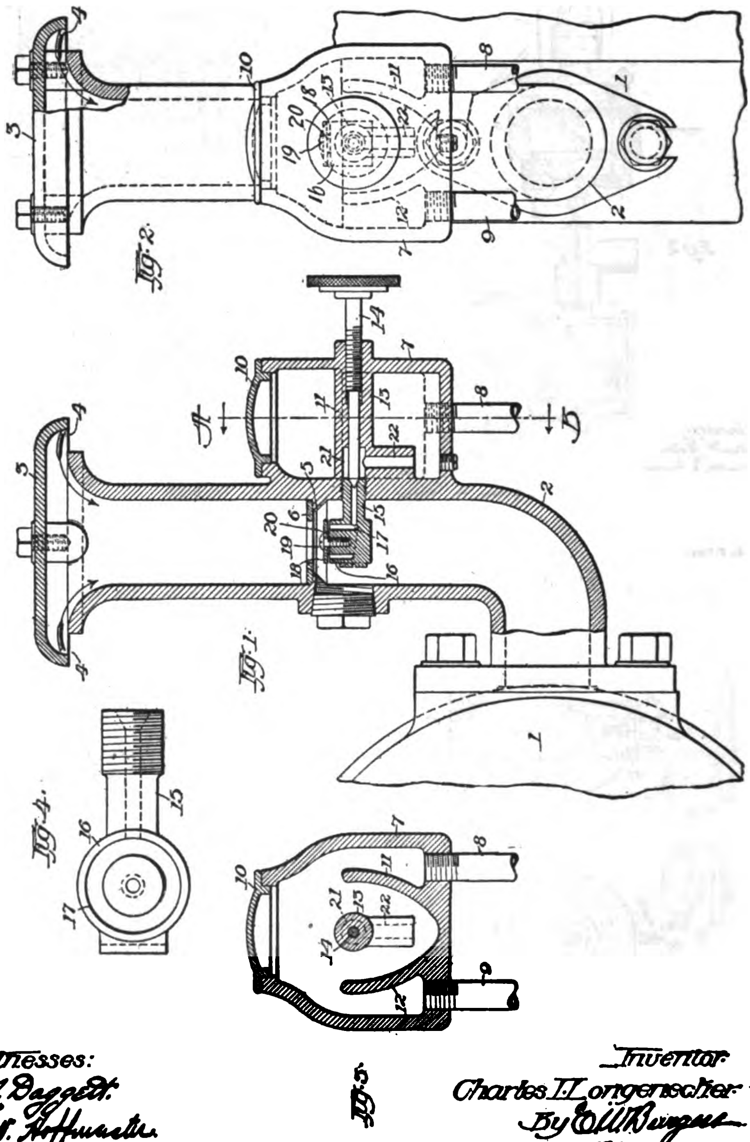
FIG. 5
FIG. 6
FIG. 7
WITNESSES
INVENTOR
ATTORNEY

No. 862,083. **PATENTED JULY 30, 1907.**

C. I. LONGENECKER.

VAPORIZER FOR EXPLOSIVE-ENGINES.

APPLICATION FILED JAN. 19, 1907.



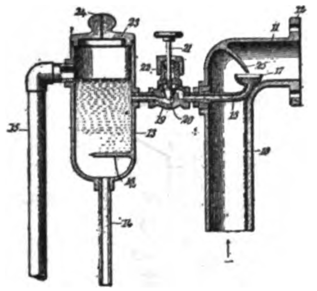
Witnesses:
J. M. Daggett.
F. W. Hoffmeister.

Inventor:
Charles I. Longenecker.
By E. W. [illegible]
Attorney.

PATENTED APR. 28, 1908.

W. L. WATRYBUS.

CARBURETER.



Inventor

By Munn & Co

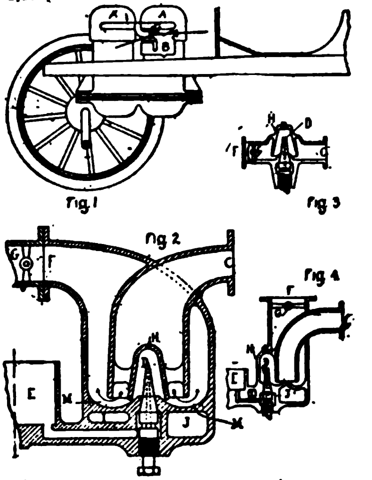
Attorneys

H. W. ALDEN.

CARBURETER.

APPLICATION FILED APR. 1910.

1,072,376. Patented Sept. 2, 1913.



Witnesses

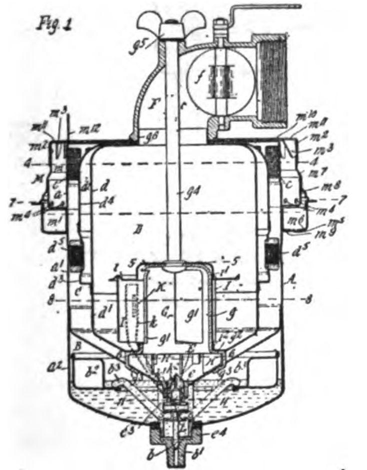
Inventor

Herbert W. Alden

H. McCORMACK.

CARBURETER.

1,141,570. Patented June 1, 1915.



Witnesses

C. M. Bond

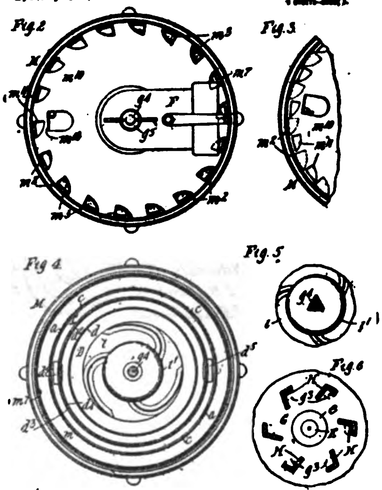
Inventor

Attorneys.

H. McCORMACK.

CARBURETER.

1,141,570. Patented June 1, 1915.



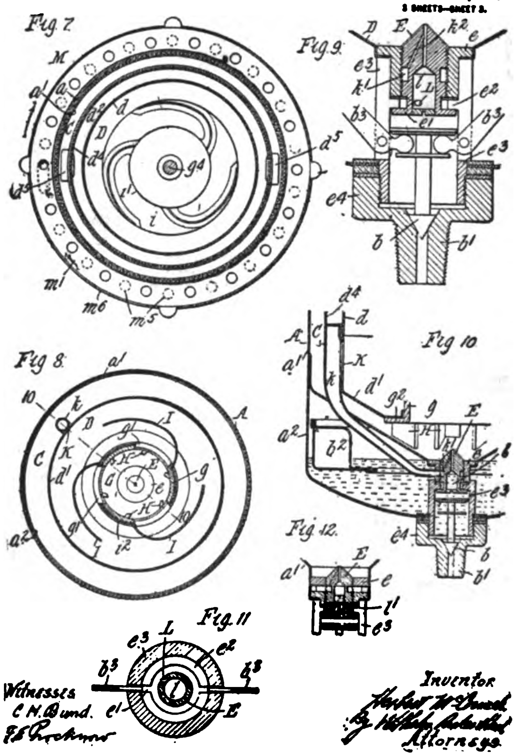
Witnesses

Inventor

Attorneys.

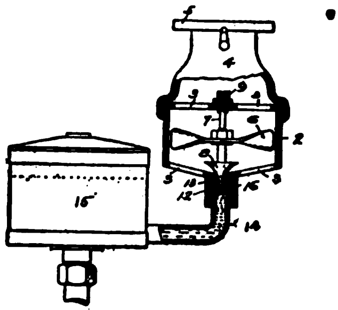
H. McCORMACK.
CARBURETER.
APPLICATION FILED AUG. 12, 1913.

1,141,570. Patented June 1, 1915.
3 SHEETS—SHEET 3.



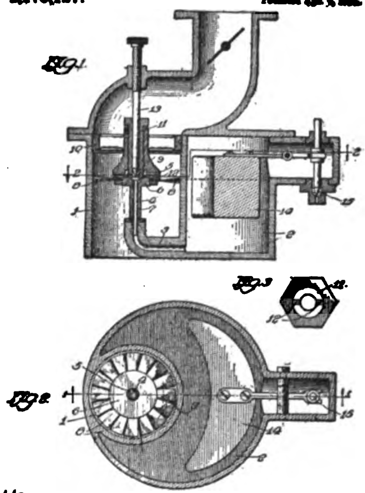
A. M. SANBORN.
CARBURETER.
APPLICATION FILED MAY 1913.

1,093,958. Patented Apr. 14, 1914.



Witnesses
Inventor
A. M. SANBORN.

1,178,127. Patented Apr. 4, 1916.



Witnesses
Inventor

page 217 (817,641, Apr. 10, 1906, Harris), because the hanging wall will prevent any increased velocity head action at the final inlet, so fuel flow will increase with air only as a result of air entrance resistance without air velocity head assistance. Quite the contrary is the object on page 217 (817,941, Apr. 17, 1906, Stute), where the air is guided directly over the fuel inlet, contributing the maximum air velocity head effect on fuel flow added to the entrance resistance.

A circular-slot form of fuel inlet is shown on page 218 (862,083, July 30, 1907, Longenecker), so arranged behind an annular air baffle as to receive a similar additive effect of air entrance resistance and velocity head. Combination of a spraying arrangement of baffle with the accelerating-cup idea is illustrated on page 219. (886,283, Apr. 28, 1908, Wayrynen.) At low-flow rates the cup remains nearly full with the air sweeping off a surface film, but a sudden increase of air flow will sweep it clear of contents, adding this volume momentarily to the fuel that flows steadily at the new higher rates due to the greater vacuum. A complete shrouding of the fuel inlet with opposed axial flow to reduce to a minimum the velocity head effect, though not eliminating it, because there is some such action at the base of the shroud, is shown on page 219. (1,072,376, Sept. 2, 1913, Alden.) Location of the fuel inlet in the center of an air vortex produced by inward flow of air between radially curved vanes in the air passage is shown on pages 219 and 220. (1,141,570, June 1, 1915, McCormack.)

Subclass 3.3—Rotating fuel spreader, air driven.—*While normally* such attachments are arranged solely as mixers, they may in some cases exert a fuel-flow influence, producing to a partial degree the action of class 2. Such is the case, for example, with the form, page 221 (1,092,953, Apr. 14, 1914, Sanborn), but not so with the form on page 221 (1,178,127, Apr. 4, 1916, Bricken). In the former the fuel is subjected to a lifting action beyond its submerged measuring restriction, which reduces the degree of submergence and increases the flow, but in the latter form no fuel is subjected to the rotating influence until it has dropped free of the passages where its flow might be affected.

Subclass 3.4, variable jet and throat relation.—This is one of the most promising means of correcting for the tendency toward richness on increasing flow rates and is illustrated in one form on page 225 (1,086,226, Feb. 3, 1914, Sassano), where the fuel inlet while fixed is acted upon by the vacuum at a hole in a tube surrounding the nozzle. This tube rises with increased flow by reason of the baffles in the tapered passage, thereby raising the hole to a higher point where the vacuum is less at a given air-flow rate than at a low point. Therefore the flow rate for fuel will not increase as fast as if its inlet were acted on by the vacuum at a fixed point in the venturi. The action is corrective as to proportionality in a qualitative sense and can be made so to a proper degree by suitably curving the tapering walls. The effect is the same as if the fuel inlet were moved to that portion of the venturi, as would by the vacuum in it, produce the correct constant proportioning flow. In a different way the same effect is secured by moving an approximation to a venturi past a fixed fuel nozzle in the form, page 225 (656,197, Aug. 21, 1900, Lumiere), a case about 14 years older.

Subclass 3.5, variable float chamber pressure.—Moving the position of the fuel inlet with respect to the throat of a tapered air passage is equivalent to adjusting the fuel-flow head to that value that would give the correct constantly proportionate flow, by operating at the point of fuel exit from the fuel passage, but it is evident that a similar corrective pressure control could be exerted at the entrance end of the fuel passage, which is the float chamber, and such is the subject matter of this subclass, the first case in which is that illustrated on page 226 (686,101, Nov. 5, 1901, Maybach), serviceable only for constant speed engines. Combination of the Venturi tube air throat, having a right-angled fuel nozzle, with the float chamber surface pressure means of compensation, is illustrated on page 226 (7[illegible]962, Oct. 20, 1903, Grouvelle & Arquembourg). By means of two calibrated holes above the fuel, one to the atmosphere and the other to the Venturi throat, the float-chamber pressure can be kept at a regularly increasing value below atmosphere as the flow rate increases. Another case of different form is that on page 226. (954,488, Apr. 12, 1910, Wolf.) Here the float chamber is brought into communication with the mixing chamber by a valve, and air entrance to the float chamber by another valve. Adjustment of these two valves will permit of the establishment of any effective head on the fuel from zero when the latter valve is shut off and the former open up to the maximum when the former is shut off and the latter open. Opening both gives an intermediate effect. Such an adjustment, however, is similar to an adjustment of an air or a fuel valve by hand, and there is no assurance that the variations in float chamber pressure with a fixed valve setting will be just what is needed to compensate for fuel flow excesses. One attempt in this direction is that on pages 226 and 227 (1,002,646, Sept. 5, 1911, Conrad), where holes at the entrance and exit of the air venturi communicate with the float chamber with a view to making its pressure automatically, the mean between them, or the vacuum half that in the mixing chamber. In this way the fuel flow is definitely corrected to a fixed degree, but there is no assurance that this is the right degree nor that the correction should be always the same fraction. Another effort to secure a definite degree of float chamber pressure change from atmosphere but in the excess direction is that on page 227 (1,064,627, June 10, 1913, Ensign), where the pressure in the float chamber is the velocity head of the air in an entrance passage, brought to bear by pitot tube and pipe connection. In addition, the air enters in a vortex, at the center of which is the fuel inlet, so placed with reference to a dome baffle as to be in a region of low vacuum, the dome also acting as throttle. Neglecting the vacuum at the fuel nozzle the effect should be the same on the fuel flow as if a fuel nozzle of the same shape were located in the same place as the Pitot tube, but pointing in the opposite direction and fed from a constant level chamber open to the atmosphere.

Adjustment of float chamber pressure to a definite degree is accomplished, pages 227 and 228 (1,074,625, Oct. 7, 1913, Johnson, Glaser & Lloyd), by connecting it with one point of a Venturi tube while the fuel inlet is located at another point. This case is of interest also because it illustrates a diaphragm-controlled fuel-level valve.

Class 4, carburetors, proportioning flow, aspirating single fuel, multiple air inlets, both fixed.—Most of the carburetors of this class have only two air inlets, and these arranged as primary and secondary, but the effectiveness of this arrangement over a single air inlet depends entirely on the details. When the two air streams enter through fixed inlets that are similar and similarly placed, the second is of no more value than a change in adjustment of either a single air or a single fuel inlet. In such a case there can be no fuel flow compensation or correction of proportions to restore a changing proportion to constancy, because the ratio of primary to secondary air will be constant and the total no different with respect to fuel than if it all entered at one point, however much the mixing may be improved. To accomplish compensation the secondary air should increase faster than the primary in ordinary arrangements to compensate for the fuel that naturally tends to increase too fast, and this requires that the resistance to entrance of the secondary be increasingly smaller than that of the primary as the total flow increases. Both kinds of arrangements are illustrated, page 229 (772,979, Oct. 25, 1904, Vaurs), being of the fixed ratio sort, primary to secondary air, page 229 (848,170, Mar. 26, 1907, Hedstrom) tending toward correction by inserting a helical resistance baffle in the primary air.

Application of a Venturi air tube type carburetor with primary and secondary air, mutually adjustable by hand to the carbureting of air under pressures greater than atmosphere, is illustrated on pages 229, 230, and 231 (991,029, May 2, 1911, Scott), without in any way interfering with the aspirating character of the fuel, because the float chamber surface pressure is equalized with that of the source of air supply. Incidentally this is an interesting form of two-cycle engine in which the crank end of the cylinder acts as air pump, permitting the open type of frame to be substituted for the then more common form of closed crank case. This form, shown on page 231 (1,159,167, Nov. 2, 1915, Breeze), goes further in seeking compensation by the use of a Venturi for both air passages, that for primary air being very small and discharging into the throat of the large secondary. A short free passage for the secondary, and a longer more resistant passage for the primary, so related that the primary helps to induce the secondary, is shown on page 231. (1,134,365, Apr. 6, 1915, Barnes.) This same case also illustrates an interesting form of low velocity or idling lifting tube, brought into action by closing the throttle, which act diverts the mixture from the low velocity main air passage to a small high velocity by-pass, helping to lift unvaporized fuel. Even though the whole arrangement is such as to conform to the principle of increasing ratio of secondary over primary air, it does not follow that the amount of change will be just what is required for compensation; it may be qualitatively proper, but quantitatively improper or inadequate.

Subclass 4.1, mixed flow.—Admission of air to the fuel passage is a direct means of compensation qualitatively correct and questionable only as to degree, because any such air reduces at once the vacuum that is inducing flow, and, therefore, reduces the flow so that if admitted to the right place and in the right degree it would constitute a satisfactory fuel-flow corrector and result in constancy of proportions when otherwise the fuel ratio would be increasing. The

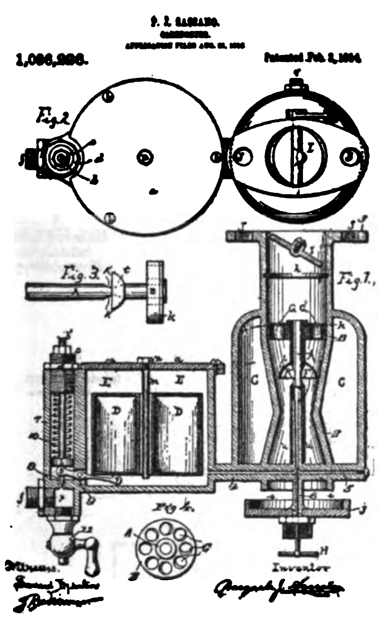
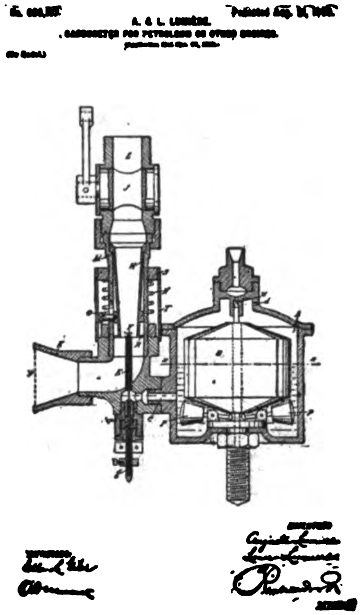


Fig. 2
Fig. 3.
Fig. 1.
Inventor



No. 741,362. PATENTED OCT. 20, 1903.
J. GROUVELLE & H. ARQUEMBOURG.
REGULATOR FOR CARBURETERS FOR EXPLOSIVE ENGINES.
APPLICATION FILED JULY 2, 1903.
NO MODEL.

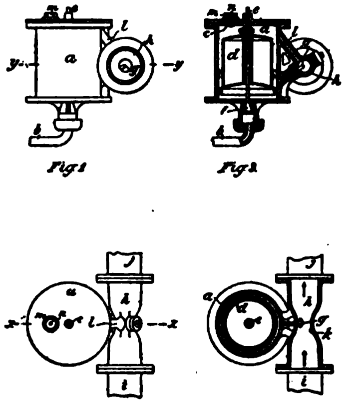
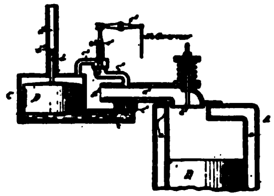


Fig 1 Fig 2 Fig 3 Fig 4

Witnesses: Edouard Carénou, Gabriel Maraan

Inventors: Jules Grouvelle, Henri Arquembourg

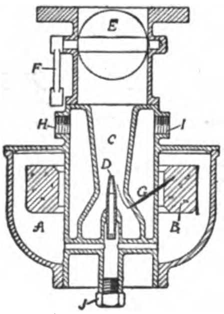
No. [illegible] Patented [illegible]
W. A. MAYBACH.
REGULATING DEVICE FOR EXPLOSION MOTORS.
[illegible]
No Model.



Witnesses: [illegible]

Inventor: Wilhelm A. Maybach by his Attorney [illegible]

A. M. WOLF
CARBURETER.
APPLICATION FILED MAY 3, 1909.
954,905. Patented Apr. 12, 1910.

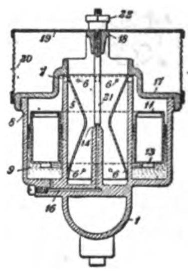


WITNESSES: Charles [illegible], [illegible]

INVENTOR: A. M. Wolf

F. CONRAD.
CARBURETER.
APPLICATION FILED FEB. 28, 1910.
1,003,646. Patented Sept. 5, 1911.
[illegible]

Fig.2

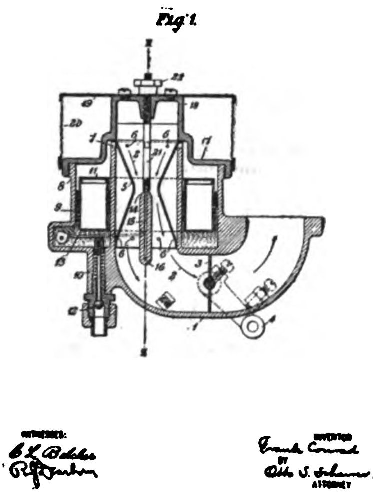


WITNESSES: C. L. Belcher, R. J. Dearborn

INVENTOR: Frank Conrad BY Otto S. Schairer ATTORNEY

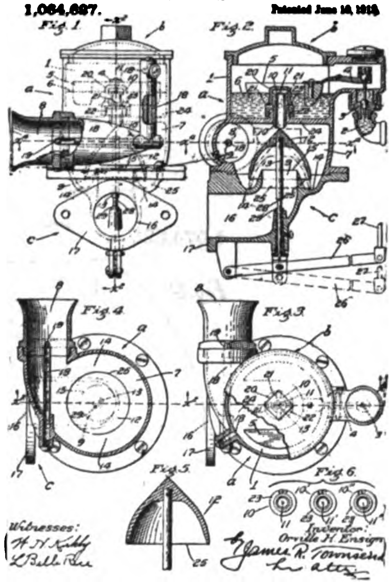
F. CONRAD.
CARBURETER.

1,002,646. Patented Sept. 5, 1911.



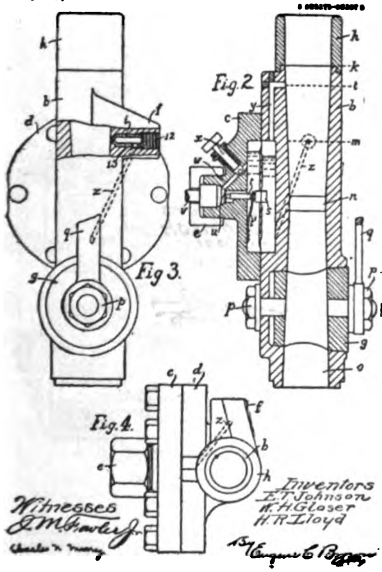
O. H. ENSIGN.
VAPORIZER.

1,064,697. Patented June 10, 1913.



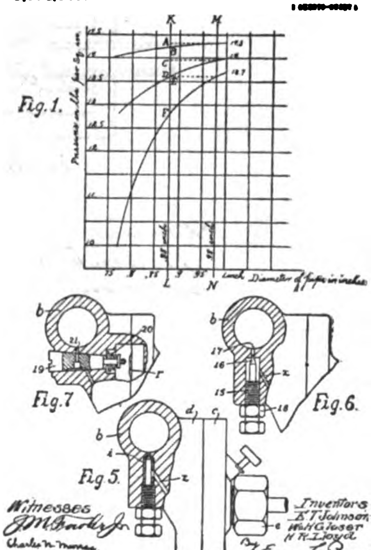
E. T. JOHNSON, W. H. GLASER & H. R. LLOYD.
CARBURETER.

1,074,695. Patented Oct. 7, 1913.



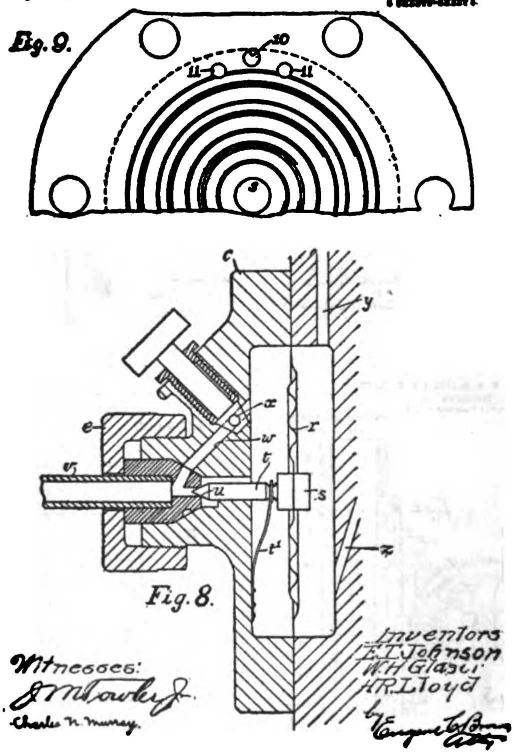
E. T. JOHNSON, W. H. GLASER & H. R. LLOYD.
CARBURETER.

1,074,695. Patented Oct. 7, 1913.

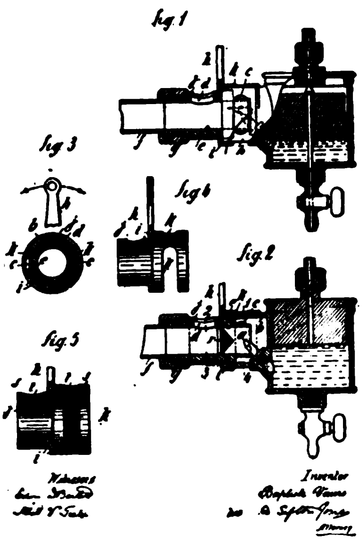


E. T. JOHNSON, W. H. GLASER & H. R. LLOYD.
CARBURETER.
APPLICATION FILED MAR. 30, 1912.

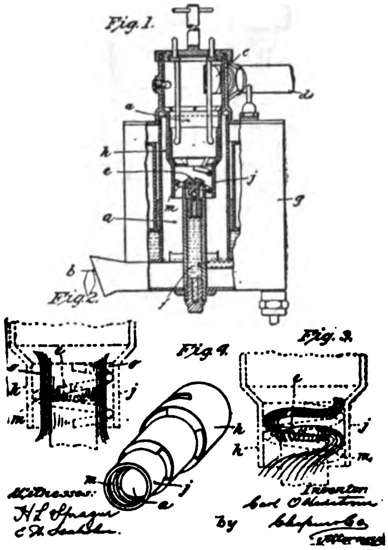
1,074,625. Patented Oct. 7, 1913.
6 SHEETS-SHEET 6.



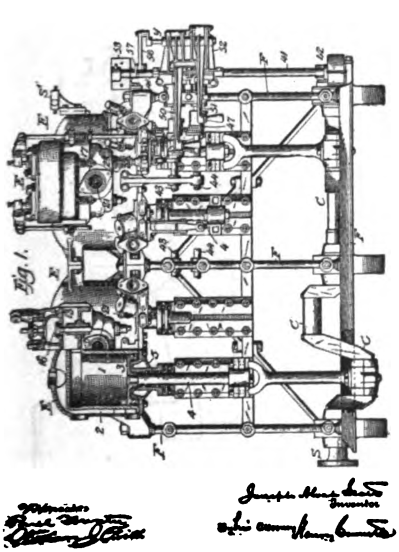
No. 772,… PATENTED OCT. …, 190…
R. VAURS.
CARBURETER FOR HYDROCARBON ENGINES.
APPLICATION FILED FEB. …, 190…



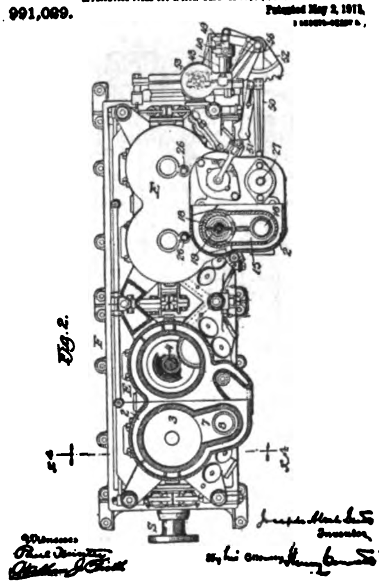
No. …,170. PATENTED MAR. …, 190…
C. O. HEDSTROM.
CARBURETER.
APPLICATION FILED JULY …, 190…



J. A. SCOTT.
INTERNAL COMBUSTION ENGINE.
APPLICATION FILED OCT 5, 1906. RENEWED JULY 26, 1909.
991,029. Patented May 2, 1911.
3 SHEETS-SHEET 1.

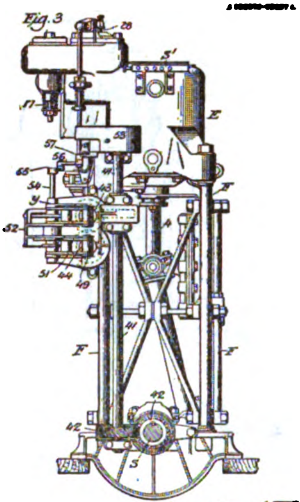


J. A. SCOTT.
INTERNAL COMBUSTION ENGINE.
APPLICATION FILED OCT 5, 1906. RENEWED JULY 26, 1909.
991,029. Patented May 2, 1911.
3 SHEETS-SHEET 2.



J. A. SCOTT.
INTERNAL COMBUSTION ENGINE.
APPLICATION FILED OCT 4, 1909. RENEWED JULY 25, 1910.

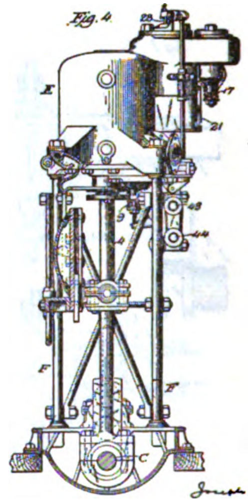
991,089. Patented May 2, 1911



Witnesses: Inventor

J. A. SCOTT.
INTERNAL COMBUSTION ENGINE.
APPLICATION FILED OCT 4, 1909. RENEWED JULY 25, 1910.

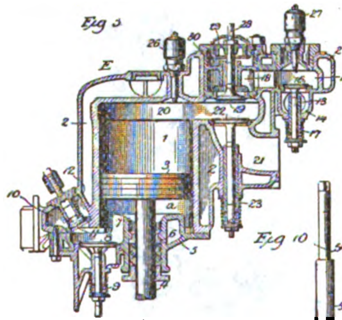
991,089. Patented May 2, 1911

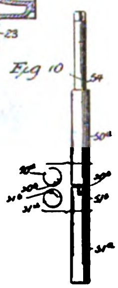


Witnesses: Inventor

J. A. SCOTT
INTERNAL COMBUSTION ENGINE.
APPLICATION FILED OCT 4, 1909. RENEWED JULY 25, 1910.

991,089. Patented May 2, 1911

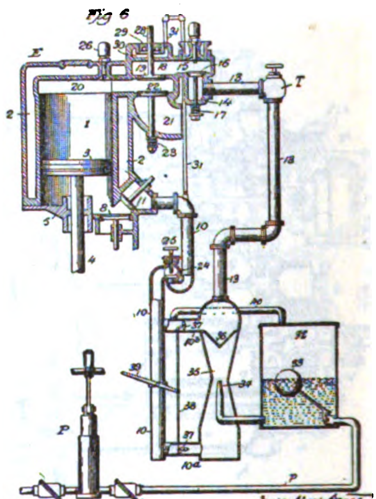




Witnesses: Inventor

J. A. SCOTT
INTERNAL COMBUSTION ENGINE.
APPLICATION FILED OCT 4, 1909. RENEWED JULY 25, 1910.

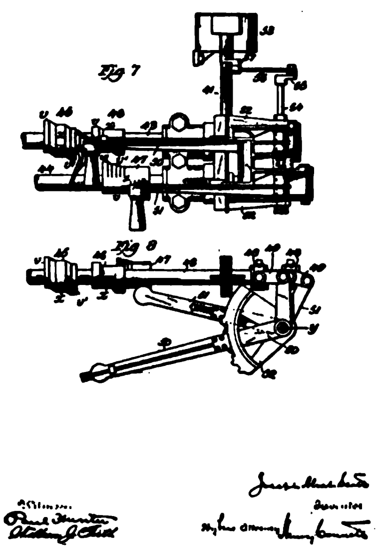
991,089. Patented May 2, 1911



Witnesses: Inventor

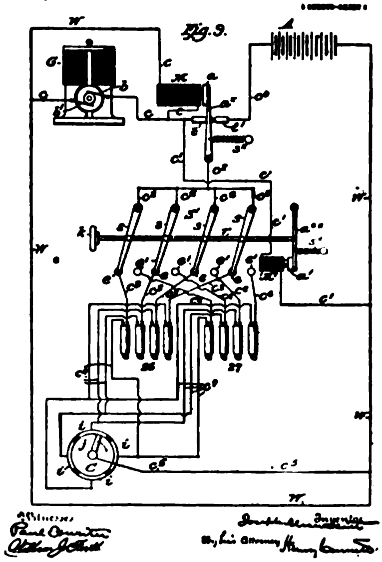
J. A. SCOTT.
INTERNAL COMBUSTION ENGINE.

991,099. Patented May 2, 1911.



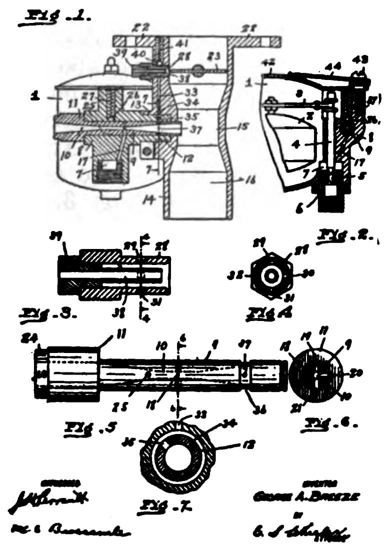
J. A. SCOTT.
INTERNAL COMBUSTION ENGINE.

991,099. Patented May 2, 1911.



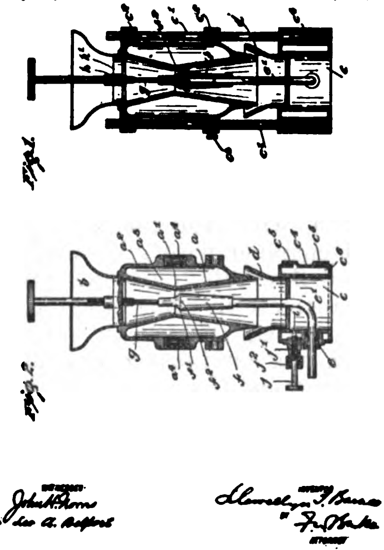
G. A. BREEZE
CARBURETER

1,159,167 Patented Nov. 2, 1915.



L. T. BARNES.
CARBURETER.

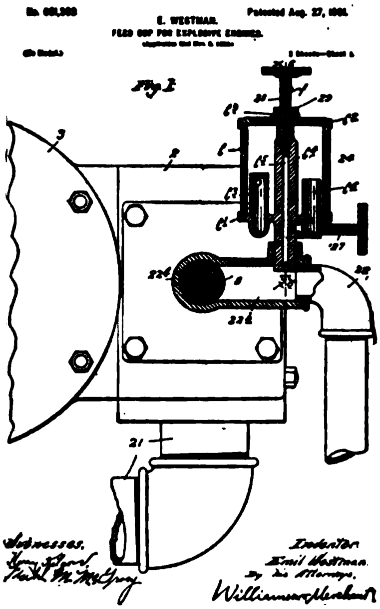
1,134,365. Patented Apr. 6, 1915.

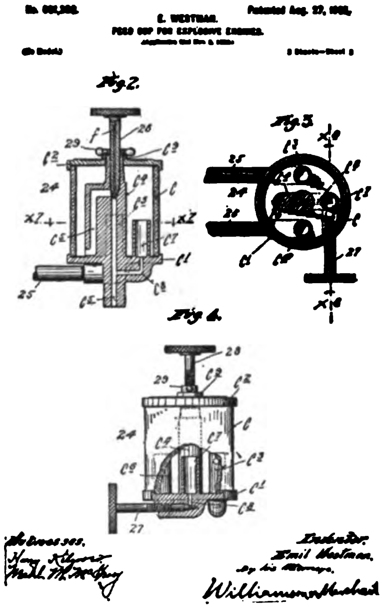


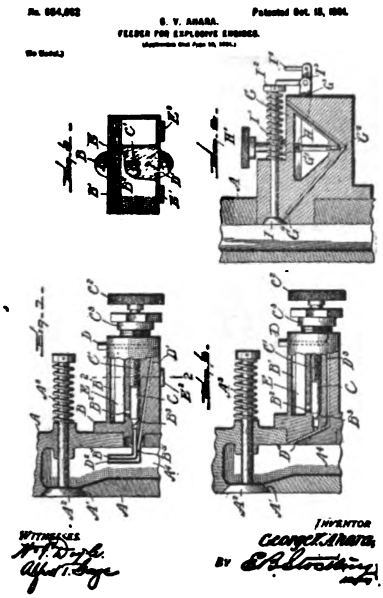
problem is, therefore, one of how, where, and to what degree the mixed-flow air should be admitted so that as the main flow increases the mixed-flow air increases regularly to just the amount needed to keep the fuel flow from increasing too fast. While the mixed-flow idea as a compensating means is one of the latest to be recognized, it has been disclosed for quite some time in connection with a single fixed fuel inlet and one other fixed air. One early case, that on page 233 (681,382, Aug. 27, 1901, Westman) shows it applied to the old overflow type of stationary engine level cup, extending its value for throttle-governed engines, where without it trouble would result, however satisfactory the operation might be for hit-and-miss governed engines. Another case of stationary engine use is that on page 233 (684,662, Oct. 15, 1901, Ahara), where it is combined with an accelerating cup brought into play and emptied after a miss to supply fuel to the extra air in the engine clearance over what is there after an explosion. A very simple form of mixed-flow type of compensator applied to a carburetor having the overflow sort of constant level chamber is shown on page 224. (686,092, Nov. 5, 1901, Lear.) Another and also simple form used in connection with a float chamber and curved venturi main air passage is that on page 233 (898,920, Sept. 15, 1908, Pierson), where, as in the case on page 233 (Westman), the fuel valve is drilled.

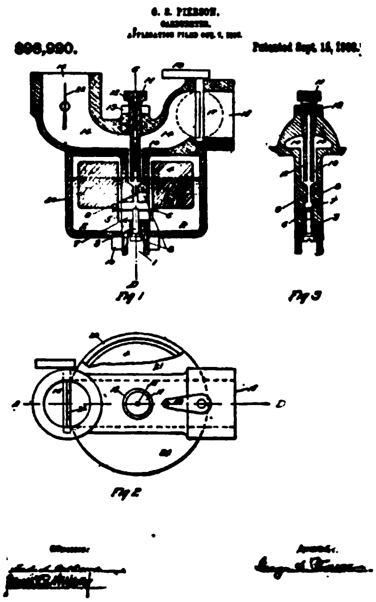
A more definite means of regulating the mixed-flow air is that on page 235 (1,121,630, Dec. 22, 1914, Holley), where the lowering of the level in the float chamber that results from high-flow rates is relied upon to admit air to the fuel passage, and the construction is used in conjunction with an accelerating cup beyond the fuel inlet. The presence of the drain hole at the low point of the mixing chamber is an indication of the difficulty in vaporizing modern gasolines, which at low-flow rates tend to accumulate and when enough has collected to suddenly overflow. In place of such drain holes it has become the practice to provide a lifting tube, extending above the throttle. A most interesting mixed-flow fuel nozzle is that on page 235 (1,130,490, Mar. 2, 1915, Delaunay & Belleville), where the amount of such air is controlled by the velocity in the throat. Another case controlled by the level in an auxiliary well, which also acts as accelerating cup, is shown on page 235. (1,149,035, Aug. 3, 1915, Doué.) Here the fuel passage is supplied from two orifices to the float chamber with a siphoning well between them, which well fills at low-flow rates only one fuel orifice supplying the nozzle. A sudden increase in demand empties the well and exposes a series of air holes through which air enters to retard the fuel flow, the number depending on the vacuum, as the second fuel orifice acts to close them against the vacuum tending to expose them.

This principle of fuel-flow compensation directly acting on the net fuel head by admission of air to the fuel passage, termed mixed flow, illustrated here in connection with a single fuel-fixed inlet and one other fixed-air inlet, will be found in use with other fuel and air inlet combinations, as is also the case with its counterpart compensating scheme, the control of float chamber pressure.


E. WESTMAN.
Fig. 1
Witnesses.
Inventor
Emil Westman.
By his Attorneys,
Williamson & Merchant


E. WESTMAN.
Fig. 2.
Fig. 3
Fig. 4.
Witnesses.
Inventor.
Emil Westman,
By his Attorneys,
Williamson & Merchant


G. V. AHARA.
Patented Oct. 18, 1904.
WITNESSES
INVENTOR
George V. Ahara,
BY


G. S. PIERSON.
CARBURETER.
896,990.
Fig 1
Fig 3
Fig 2

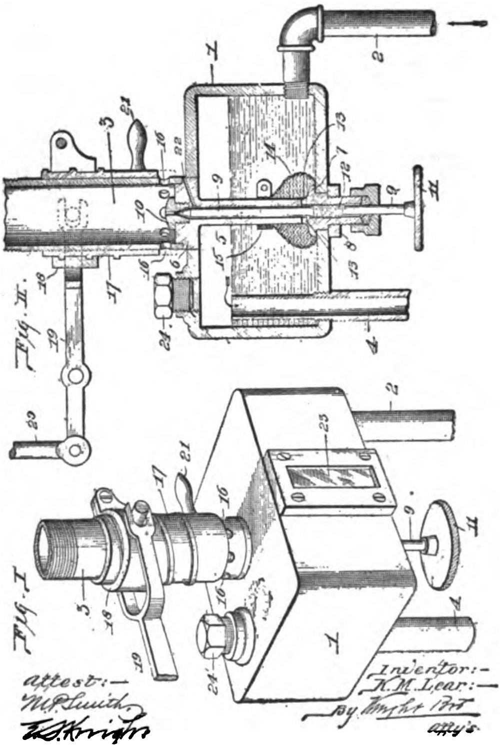
No. 686,092. Patented Nov. 5, 1901.

K. M. LEAR.

VAPORIZER FOR GASOLENE ENGINES.

(Application filed Feb. 14, 1901.)

(No Model.)



C. M. ROLLET.
CARBURETER.
APPLICATION FILED JULY 10, 1911.

1,121,630. Patented Dec. 22, 1914.

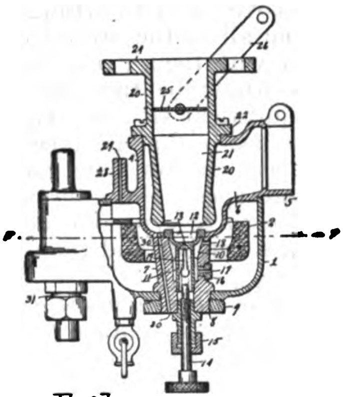


Fig.1.

C. M. ROLLET.
CARBURETER.
APPLICATION FILED JULY 10, 1911.

1,121,630. Patented Dec. 22, 1914.

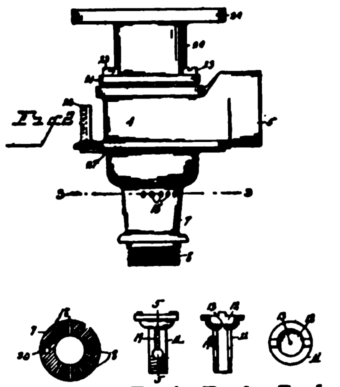
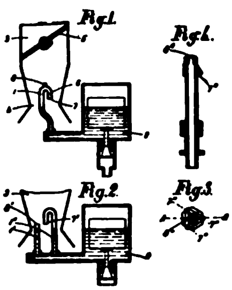


Fig.3. Fig.4. Fig.5. Fig.6.

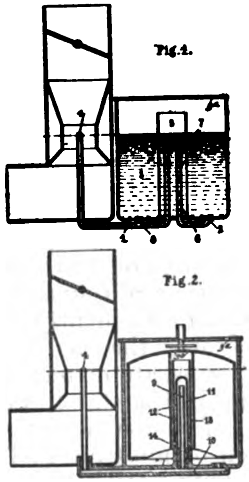
R. DELAUNAY-BELLEVILLE.
CARBURETER.
APPLICATION FILED MAR. 26, 1906.

1,130,490. Patented Mar. 2, 1915.



E. E. E. DOUÉ.
CARBURETER.
APPLICATION FILED JAN. 2, 1912.

1,149,035. Patented Aug. 3, 1915.



WITNESSES

INVENTOR
E.E.E. Doué
BY
ATTORNEY

Class 5—Carburetors, proportioning flow, aspirating, multiple fuel single air inlets, both fixed.—Just as two or more fixed air inlets, differently situated or having different flow characteristics associated with a single fixed fuel inlet may be made to act in a compensating manner, so also is it possible to fix more than one fuel inlet in a single fixed air passage, the problem being to discover such an arrangement as will result in a combined fuel flow from all of the several differently situated fuel inlets, that will increase with the air in a constant ratio instead of an increasing ratio, as would be the case if all were similarly situated, and therefore equivalent to one. In some cases, however, the two fuel inlets are arranged so that a correct ratio of fuel to air can be obtained at low speed or low flow rates by manual adjustment, and also again at high speed, the intermediate ranges being more or less uncertain. The three typical groups of this class are each designated by a subclass number and the several cases collected under the subclasses.

Subclass 5.1—Main fuel inlet with supplementary high-speed jet.—Two fuel inlets located at different points in an air venturi, one supplying all or practically all the fuel for low speed and the other coming into action as the flow rate increases, is the combination illustrated on page 237 (1,079,634, Nov. 25, 1913, Burchartz), in which also the accelerating cup is incorporated.

Subclass 5.2—Main fuel inlets with supplementary idling jet.—Addition to a single plain fixed fuel and air inlet, of a second fuel inlet above the throttle, arranged to act on closed throttle when the main jet is supplying inadequate fuel or none at all, is illustrated on page 238 (995,074, June 13, 1911, McCarthy).

Subclass 5.3—Fuel standpipe.—Instead of fixing the proportions by manual adjustment or location of two fuel inlets for two limiting flow rates, as in the previous cases, without any definite effort to secure graduation between them, the regular graduation may be the main object. Usually the method employed here is that designated as the standpipe, illustrated in its multitubular form on page 239 (1,093,343, Apr. 14, 1914, McAndrews), which is only a step in this direction, as it has but three fuel tubes with outlets at different levels in the air passage, therefore constituting what might be called a three-point adjustment. It is evident that with this arrangement the correct proportions could be secured for steady flow at least for three separate flow rates. Still more tubes, or passages formed in the walls of a tube with outlets at different heights, the highest one being above the throttle, are found on page 239 (1,148,378, July 27, 1915, Grapin & Grapin). Evidently any number could be so fixed; the more there are, however, the smaller each becomes, the less easy it is to secure the several separate manual adjustments, and the more the tendency for the fuel in the standpipes to surge and oscillate on pulsating flow, which, of course, defeats the purpose. The fact that this sort of disposition of multiple fuel inlets, dissimilarly placed, is usually associated with variable air inlets is an indication of difficulty with or objections to a single air inlet.

J. G. BURCHARTZ.
CARBURETER.
APPLICATION FILED JULY 26, 1912.

1,079,684. Patented Nov. 26, 1913.

Fig. 1.

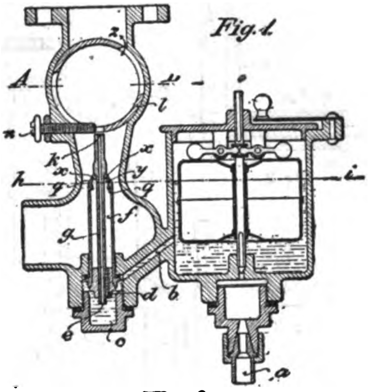
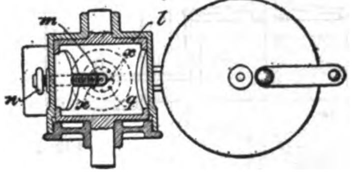


Fig. 2.



Witnesses:

Inventor

per

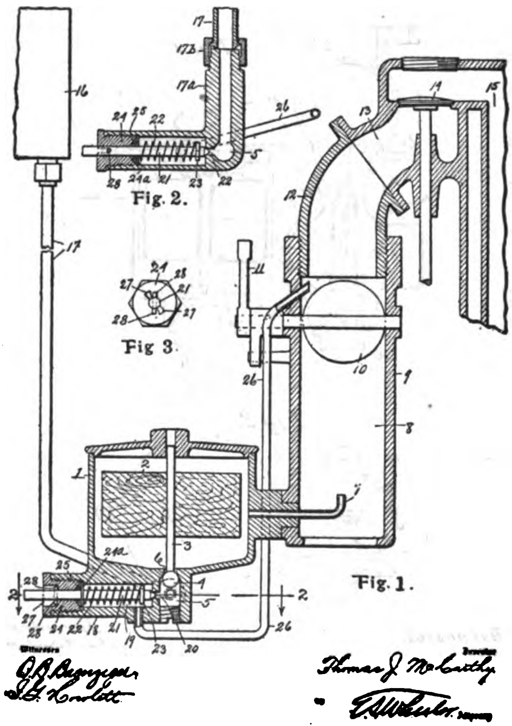
Attorney.

T. J. McCARTHY

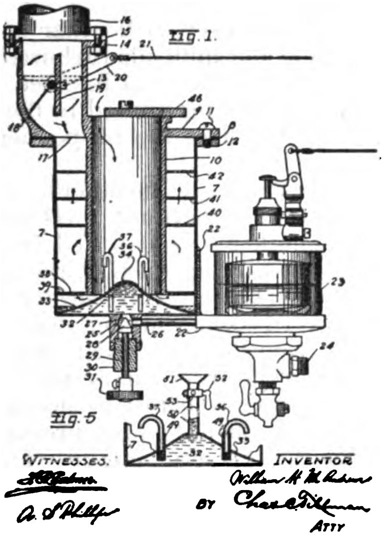
PRIMING ATTACHMENT FOR CARBURETERS

APPLICATION FILED MAY 31 1910

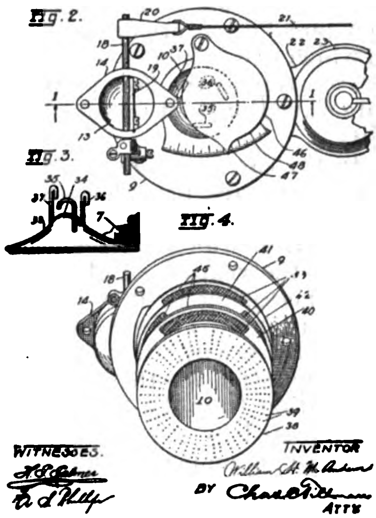
995,074. Patented June 13, 1911.



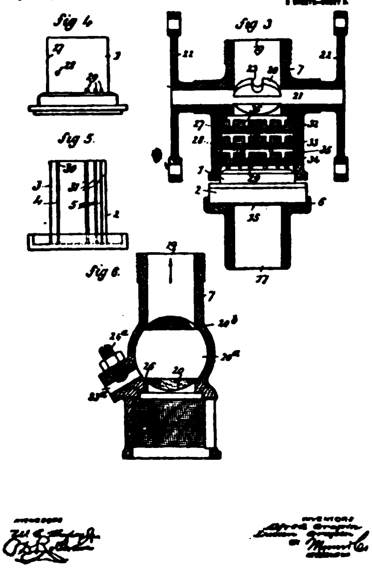
1,098,343. Patented Apr. 14, 1914



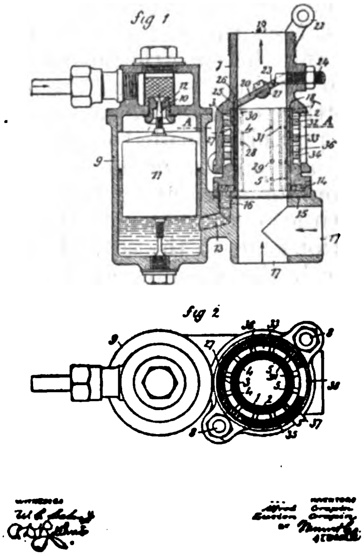
1,098,343. Patented Apr. 14, 1914



1,146,378. Patented July 27, 1915.



1,146,378. Patented July 27, 1915.



Class 6, carburetors, proportioning flow, aspirating, multiple fuel and multiple air inlets, both fixed.—That suitable dispositions of differently situated multiple fuel and air inlets offers possibilities of compensated proportioning flow is clear from the preceding examination of several air inlets for a single fuel and of several fuel inlets for a single air and along similar lines. However, still other and new possibilities are opened up in the double and multiple carburetor in which two or more complete carburetors may be brought into action successively as the flow rates increase, any one being limited to flow-rate variations not great enough to seriously affect the proportionality.

In the case on page 244 (1,097,165, May 19, 1914, Bucherer), two fuel inlets are provided—one supplied from a constant level cup open to the atmosphere, the other forms another such cup, fed from the first, in which the surface pressure is less, being open to the air and to the venturi air throat, so that the surface pressure decreases with increasing air-flow rates, and the level becomes higher than in the float cup. The sum of the fuel flow from these two will clearly not increase with air flow as fast as that from an ordinary jet, but it is a question whether or not the compensation is correct in amount. Aspiration from the fuel inlet with equalized float-chamber pressure is promoted by a second small air inlet directly crossing it. This is a case of compensation by positioning of inlets.

Subclass 6.1, double carburetor, progressive, by throttle.—Naturally two fuel inlets, each in its own air inlet, can be proportioned or adjusted to give correct proportions for at least two different flow rates, and this is the idea of the double carburetor, which may have different flow characteristics and proportions at other rates, depending on the form of each of the two elementary carburetors. If the engine speed be constant, as with governor-controlled stationary engines, then there is a more or less definite relation between the flow rate and the throttle position; but this is not the case with variable speed engines, such as the automobile class, where for any given throttle position the speed and flow rate may vary most widely. The propeller loaded engine, marine or aero, falls between. These facts are important, because in the first group there would be some reason for associating the successive action of the separate parts of multiple carburetors with the throttle because of the flow-rate relation; but in the second class there is no rational basis for such a control, the vacuum as a direct result of flow rate replacing the throttle in validity. In fact, no matter what the type of engine as to speed and load variations vacuum change is a direct function of flow-rate change, and is a more rational and fundamental actuating means than the throttle.

The cases of this subclass of two carburetors brought into action successively by the throttle must be regarded as excluded from application to variable speed engines where speed is as much a matter of resisting torque as of throttle position. A small complete carburetor, suitable in size for idling with the throttle closed, associated with a larger single fixed inlet carburetor for normal working, the idler remaining in action, constitutes one special form of this double carburetor throttle, and is controlled is illustrated on page 245. (1,002,699,

Sept. 5, 1911, Jouffret & Renee.) This can be regarded as somewhat more legitimate than the double form with throttle connected so the smaller one is advanced, shown on page 246. (1,011,694, Dec. 12, 1911, Winton.) Two independent carburetors, a smaller one acting as idler for low speed, are combined in such a way that the outlet of the idler is led to a separate branched header within the main header of a vertical multicylinder engine, the idler branches ending directly at the inlet valves on page 245. (1,069,502, Aug. 5, 1913, Wadsworth.) The object of this is to prevent the dilution of the small idling charges by the large volume of whatever may be in the main header, and yet not interfere with combined action of both when conditions are favorable. Closed throttle leaves only the idler in action; wide-open throttle permits both to act.

Subclass 6.2, multiple carburetor, progressive by throttle.—Such cases as fall under this class are the same as the last except as to number of elements, page 247 (759,624, May 10, 1904, MacMulkin), showing five, brought into action successively by the rotation of a barrel throttle having five slots of different length. A peculiar form of fuel inlet passage is here shown, consisting of small slots cut in a tapered plug screwed down tight on a tapered seat. Six elements, each with one fixed fuel, having fixed primary and secondary air, with a rotating plate throttle, are shown on page 247. (948,612, Feb. 8, 1910, Krause.) In multiple carburetors, the succession of which is throttle controlled, speed changes may build up flow rates that are excessively high for a given throttle opening, and thereby bring about just the sort of undesirable enrichment that the multiplicity is supposed to avoid. To avoid this a vacuum-controlled choke or automatic secondary speed-governing throttle may be introduced, as on page 248. (1,018,262, Feb. 20, 1912, Neal.) Should the engine speed become excessive for a given exposure of jets, the spring-resisted piston valve moves across the mixture outlet and closes it enough to induce the vacuum on, and hence the flow through the passages. The effect is similar to a vacuum control of succession. Three, one leading above the throttle and the second with an accelerating cup, are provided on pages 248 and 249 (1,158,589, Nov. 2, 1915, Thurot), but involving throttle-controlled succession.

Subclass 6.3, double carburetor, progressive by vacuum.—Vacuum being a more rational basis than throttle movement for controlling succession, this class is more interesting, and the form page 250 (1,176,627, Mar. 21, 1916, Ver Planck) being so recent, is doubly interesting as an illustration. Here two fixed fuel inlets are each located in separate venturi throats of different size and fed from overflow types of level cups, the overflow from one feeding the other. The smaller acts for low-flow rates, and can evidently be made to give correct proportions for at least one rate. When the vacuum exceeds a predetermined value a check valve controlling the outlet of the second opens and establishes flow through the larger passage, which has a second venturi throat, the vacuum at which is immediately brought into action and used to hold the check valve from chattering by a pipe connection to a piston attached to the check valve. Provision for hot and cold air and a multitubular form of mixer are also provided. At some higher speed or flow rate the

proportions can evidently be made correct again, but the proportionality in the intermediate ranges depends on the characteristics of the form of each single carburetor independently, which must be the same as for those of class 3.

Subclass 6.4, multiple carburetor, progressive by vacuum.—As the number of separate complete carburetors is increased, the proportionality can be made quite correct at a larger number of points in the flow range, and this is the object of the cases of this subclass, with, of course, an increase in complication and number of parts as an offset. Five separate venturis, with single fixed air and fuel passages are provided on page 251 (871,320, Nov. 19, 1907, Bollee), brought into action by one piston valve vacuum actuated against its spring. Six fixed fuel inlets, each in a fixed cylindrical air passage, are brought in successively by the vacuum lift of a series of differently weighted outlet check valves, gravity loaded, as shown on page 252. (1,072,733, Sept. 9, 1913, Kaltenbach.)

To cause as high a flow rate to take place through a single fixed passage as through a series of separate passages with vacuum-controlled outlets will involve a very much greater vacuum at the outlet, and therefore reduce the absolute pressure at which the engine receives its charge, with corresponding reduction of volumetric efficiency and power. This valuable feature of such a series of passages, vacuum controlled at their outlets, is also characteristic of all that class of carburetors that have automatic air-inlet valve for any number of passages, including a single one, so these have something in common with the class here under discussion.

Subclass 6.5—Mixed flow.—As pointed out in dealing with mixed flow in carburetors with a single fuel inlet, this valuable direct compensation is applicable to arrangements of more than one fuel inlet. The first case of this class, that on page 253 (907,953, Dec. 29, 1908, Bavery), provides two main fuel inlets, both at the same point in the throat of an air venturi, and a third above the throttle. One of the main fuel inlets is of the plain type that in a fixed air passage tends to flow excessively fast with reference to the air at increasing flow rates. The other compensates by its mixed-flow action at high rates and plain flow at lower rates, being fed from a chamber having an atmospheric vent to which fuel from the float chamber is supplied through a calibrated opening. This auxiliary fuel chamber also has a tube leading to the third inlet above the throttle and acts in addition as an accelerating cup. On closed throttle there is no flow through either of the main inlets because of inadequate air-throat vacuum, the accelerating cup is full, and the idling jet in action. Opening of the throttle throws this jet out and brings in both the main jets, that supplied from the accelerating cup gradually decreasing in flow as the fuel head supplied to it falls in the accelerating cup and faster later on as air enters as well. A somewhat similar action results with the slightly different structure on pages 253 and 254 (998,123, July 18, 1911, Scaife), which also has three fuel inlets, one above the throttle, and two main, which merge into one at their tops. An accelerating cup feeds the idling jet and the second main or mixed-flow jet, but instead of securing its fuel directly from the float chamber the fuel passes through the same measuring passage

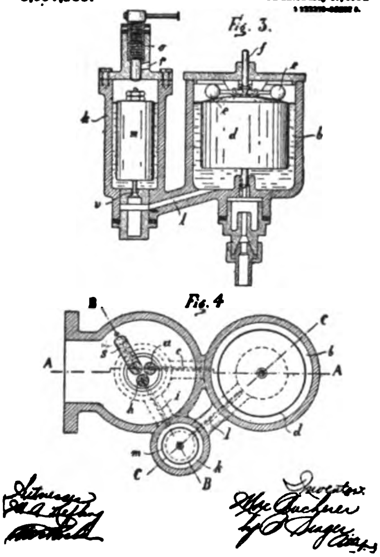
as supplies the main jet. Accordingly there is a possibility that both main nozzles may act as mixed-flow passages at high-flow rates. On page 254 (1,002,700, Sept. 5, 1911, Joffret & Renee) there are but two fuel inlets, one main and one idling above the throttle, the main acting as a mixed-flow passage at high rates. This is also the case on page 254 (1,063,148, May 27, 1913, Anderson), but in the latter case the idling jet is fed not from the accelerating cup but from a separate connection to the float chamber. The feeding of main mixed-flow jet and idling jet from an accelerating cup having a single float-chamber connection, is illustrated on page 255 (1,090,047, Mar. 10, 1914, Goudard & Muenesson), and a case of accelerating cup alternately feeding fuel to the idling jet or mixed-flow air to the main jet is shown on page 255 (1,109,974, Sept. 8, 1914, Fagard). Incorporation of the alternate-flow passages directly in the fuel nozzle is shown on page 255 (1,170,348, Feb. 1, 1916, Schüttler), where the idling jet gets fuel from the same calibrated float-chamber orifice as feeds the main jet and some air from the main jet hole on closed throttle. On open throttle the flow reverses; at the idling end of the nozzle fuel enters the main air at the Venturi throat, being modified by air received from the idling end of the nozzle, escaping with the fuel. A similar case of incorporation of all passages in a sort of multiple-walled and orificed-fuel nozzle is that on pages 255 and 256 (1,170,416, Feb. 1, 1916, Claudel), where a vertical nozzle is set for parallel flow in a bend of a fixed air passage, so that at various heights the vacuum is different and by reason of holes and multiple walls a compensating mixed flow is accomplished.

One main and one idling fuel inlet fed from a single connection to the float chamber, to which the accelerating cup is also attached, is shown on page 256 (1,175,536, Mar. 14, 1916, Longuemare), the fuel-measuring orifice being located before the whole. Here the accelerating cup alternately acts as auxiliary fuel feed, on opening the throttle, and as mixed-flow air passage, to correct the excess-flow tendencies of the main jet at high rates. A case of incorporation of the two fuel passages and a mixed flow in the fuel valve stem is shown on page 256 (1,183,019, May 16, 1916, McGuire), where the lower and manually adjustable fuel inlet serves for low flow rates and the higher one is brought into action at higher rates, with mixed-flow compensation from the hole through the stem fitted with an adjusting valve.

Subclass 6.6, fuel standpipe.—The bringing into action of successively higher fixed fuel inlets as the vacuum increases, associated with more than one fixed air inlet, without mixed flow, is another means of compensation already examined for single air inlets. On pages 257 and 258 (927,211, July 6, 1909, Bennett), a single fuel standpipe has a vertical row of perforations and is open at the top to the atmosphere. At low flow rates only the lower fuel holes act, all the rest feeding air into the main stream, but at high rates the fuel issues from more and higher holes and from lower holes at higher rates, because of the head increase. The free top air acts as a compensator to some degree, because without it the fuel would certainly rise higher and flow faster.

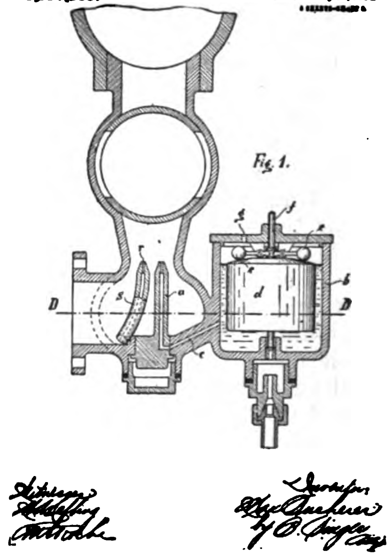
M. BUCHERER.
SPRAY CARBURETER.
APPLICATION FILED JULY 5, 1910.

1,097,165. Patented May 19, 1914.
[illegible]



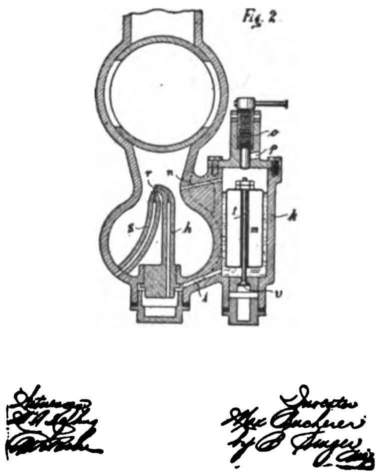
M. BUCHERER.
SPRAY CARBURETER.
APPLICATION FILED JULY 5, 1910.

1,097,165. Patented May 19, 1914.
[illegible]



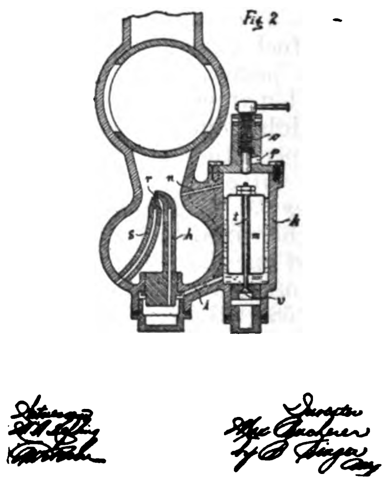
M. BUCHERER.
SPRAY CARBURETER.
APPLICATION FILED JULY 5, 1910.

1,097,165. Patented May 19, 1914.
[illegible]



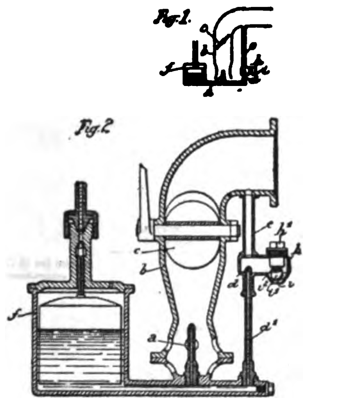
M. BUCHERER.
SPRAY CARBURETER.
APPLICATION FILED JULY 5, 1910.

1,097,165. Patented May 19, 1914.
[illegible]



H. V. J. JOUFFRET & J. M. RENDÉ.
CARBURETER.
APPLICATION FILED AUG 14, 1909.

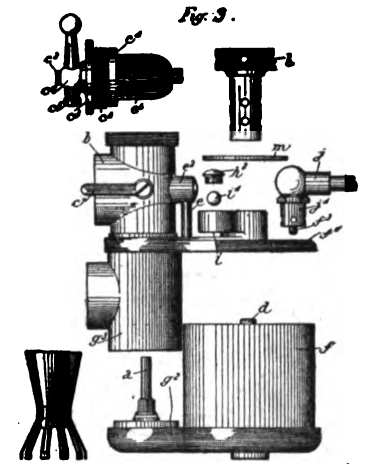
1,002,699. Patented Sept. 5, 1911.



Witnesses
Inventors
Henri V. J. Jouffret.
Jules M. Rendé.
By James L. Norris
Atty.

H. V. J. JOUFFRET & J. M. RENDÉ.
CARBURETER.
APPLICATION FILED AUG 14, 1909.

1,002,699. Patented Sept. 5, 1911.



Witnesses
Inventors
Henri V. J. Jouffret.
Jules M. Rendé.
By James L. Norris
Atty.

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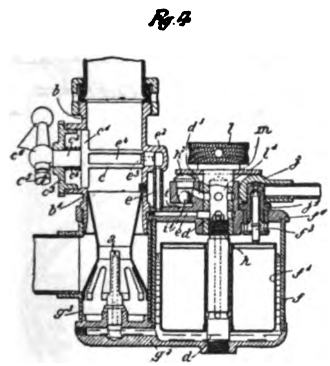
APPLICATION FILED AUG 14, 1909.

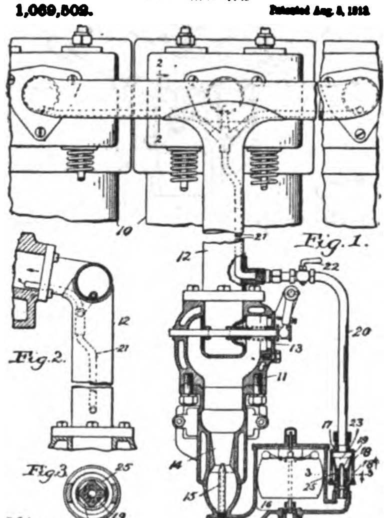
1,002,699. Patented Sept. 5, 1911.



Witnesses
Inventors.
Henri V. J. Jouffret.
Jules M. Rendé.
By James L. Norris
Atty.

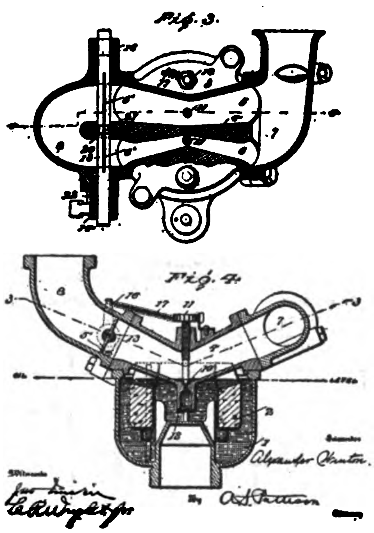
G. R. WADSWORTH.
PRIMING DEVICE FOR INTERNAL COMBUSTION ENGINES.
APPLICATION FILED OCT. 6, 1911.

1,069,502. Patented Aug. 5, 1913.

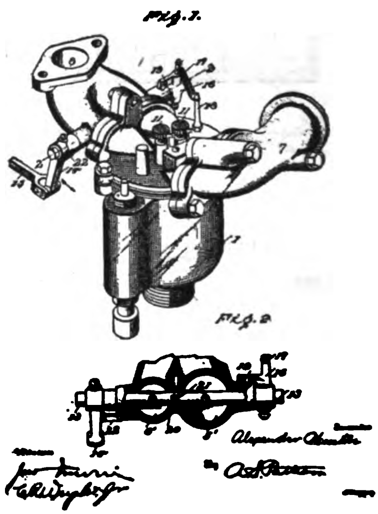


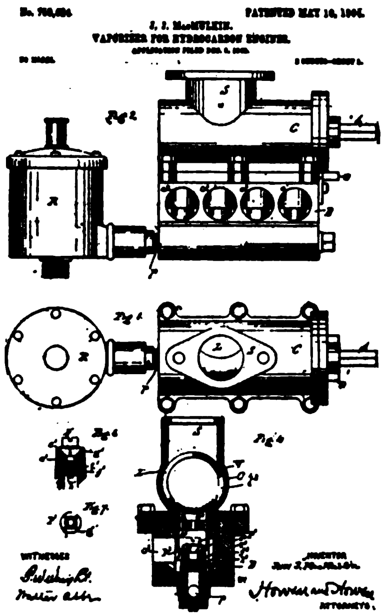
Witnesses
H. R. Sullivan
Inventor
George R. Wadsworth
by Thurston & Kwis
Attorneys

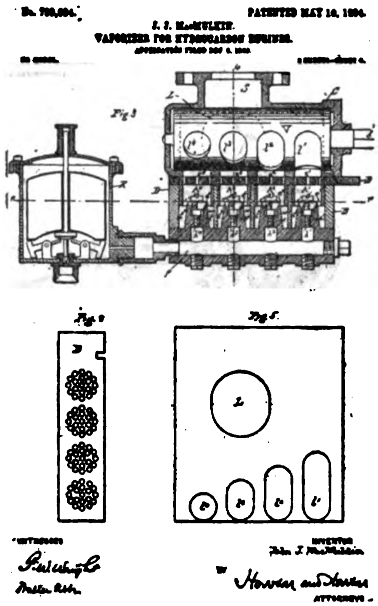
1,011,694. Patented Dec. 12, 1911.

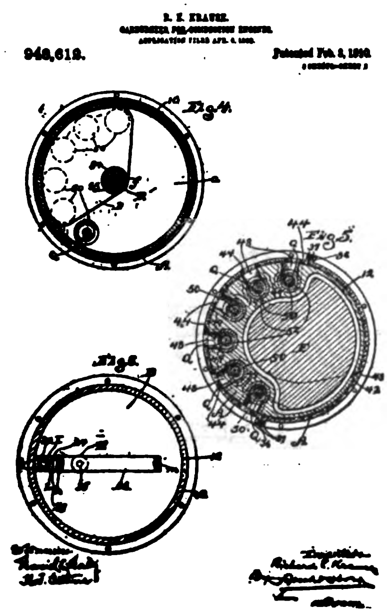


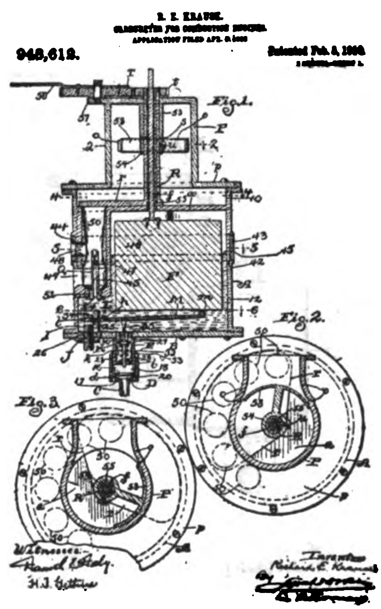
1,011,694. Patented Dec. 12, 1911.







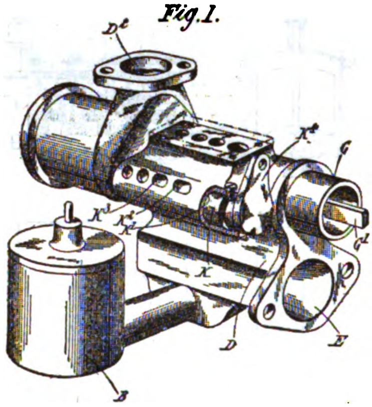




H. A. NEAL.

1,018,262. Patented Feb. 20, 1912.

Fig. 1.

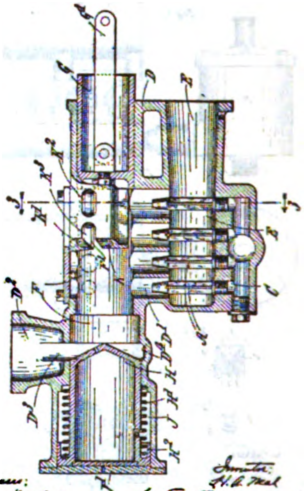


Witnesses: Inventor: H. A. Neal

H. A. NEAL.

1,018,262. Patented Feb. 20, 1912.

Fig. 2

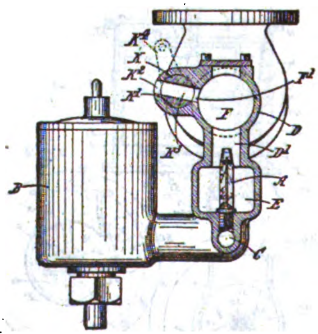


Witnesses: Inventor: H. A. Neal

H. A. NEAL.

1,018,262. Patented Feb. 20, 1912.

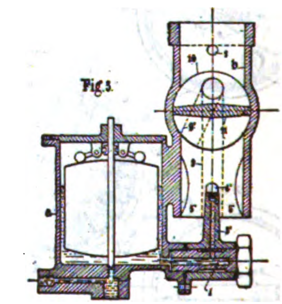
Fig. 3.



Witnesses: Inventor: H. A. Neal

J. L. T. ...

1,158,580. Patented Nov. 2, 1915.



Witnesses: Inventor

J. L. T. THUROT.
CARBURETER.
APPLICATION FILED DEC. 19, 1912.

1,158,589. Patented Nov. 2, 1915.
2 SHEETS—SHEET 1.

Fig.1.

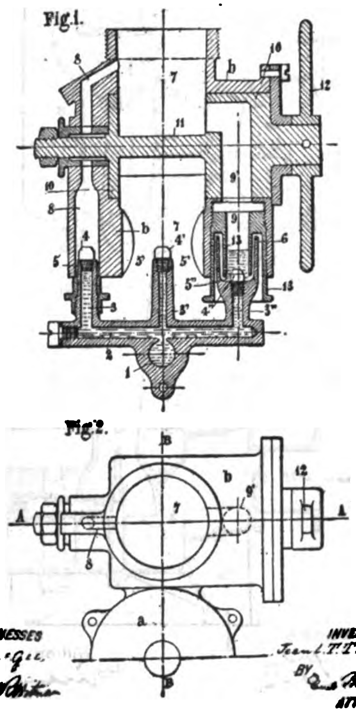


Fig.2.

WITNESSES

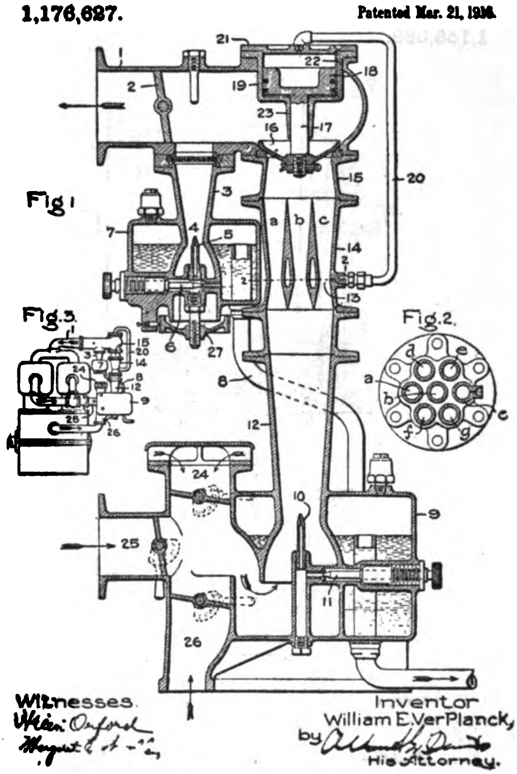
INVENTOR

BY

ATTORNEY

W. E. VER PLANCK.
CARBURETER.
APPLICATION FILED FEB 29, 1912.

1,176,627. Patented Mar. 21, 1916.



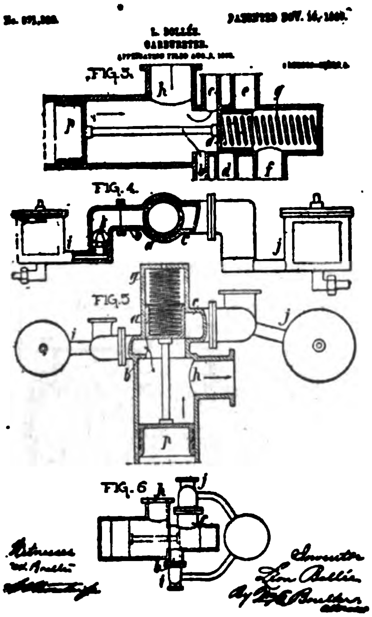


FIG. 3.
FIG. 4.
FIG. 5
FIG. 6

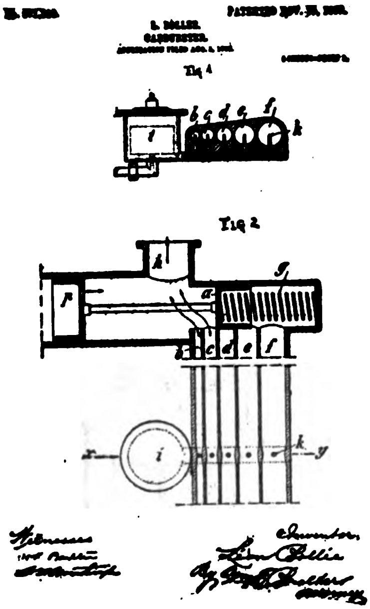
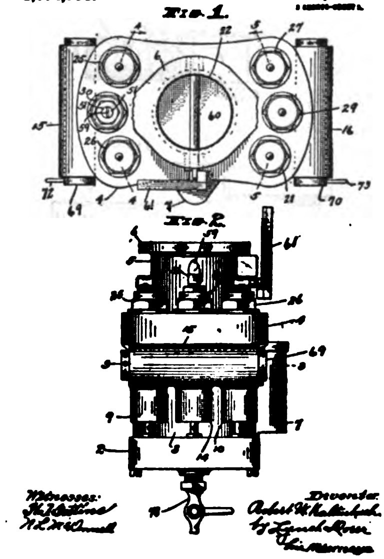


Fig 2

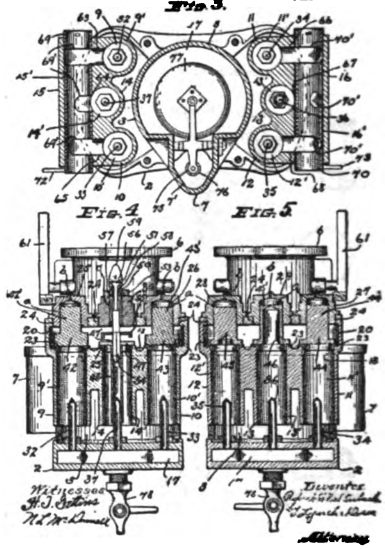
R. W. KALTENBACH.
CARBURETER.
APPLICATION FILED MAY 29, 1908.

1,072,733. Patented Sept. 9, 1913.



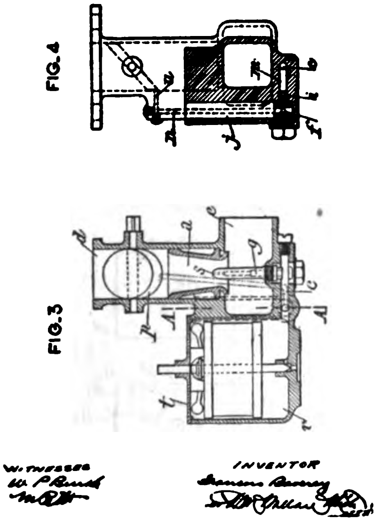
R. W. KALTENBACH.
CARBURETER.
APPLICATION FILED MAY 29, 1908.

1,072,736. Patented Sept. 9, 1913.



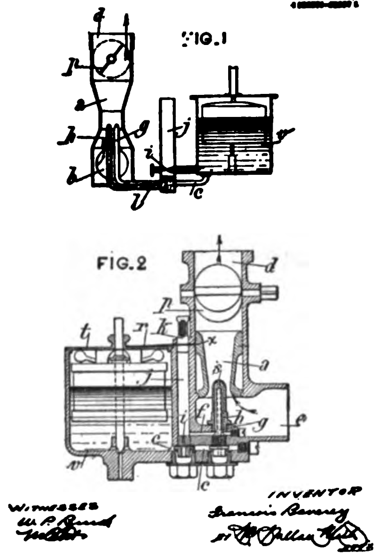
F. BAVERY.
CARBURETER FOR EXPLOSION MOTORS.
APPLICATION FILED MAR. 26, 1907.

907,953. Patented Dec. 29, 1908.
3 SHEETS—SHEET 2.



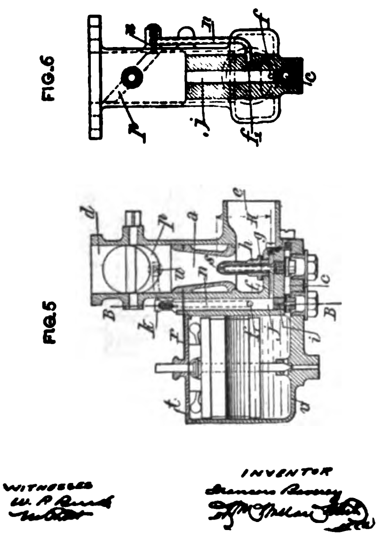
F. BAVERY.
CARBURETER FOR EXPLOSION MOTORS.
APPLICATION FILED MAR. 26, 1907.

907,953. Patented Dec. 29, 1908.
3 SHEETS—SHEET 1.



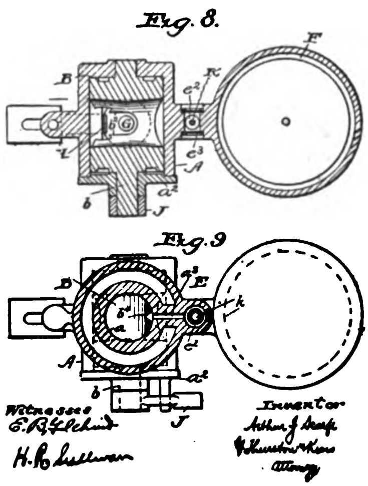
F. BAVERY.
CARBURETER FOR EXPLOSION MOTORS.
APPLICATION FILED MAR. 26, 1907.

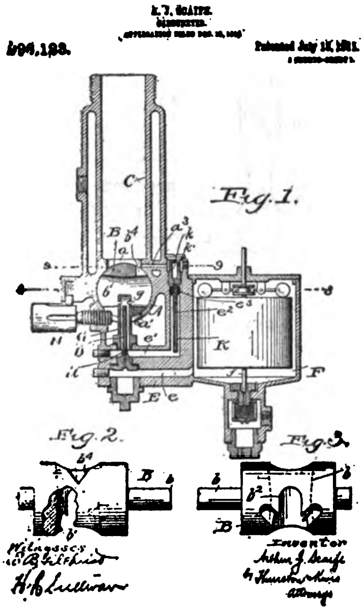
907,953. Patented Dec. 29, 1908.
3 SHEETS—SHEET 3.

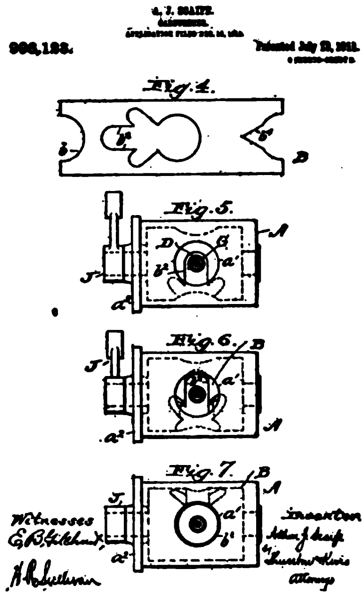


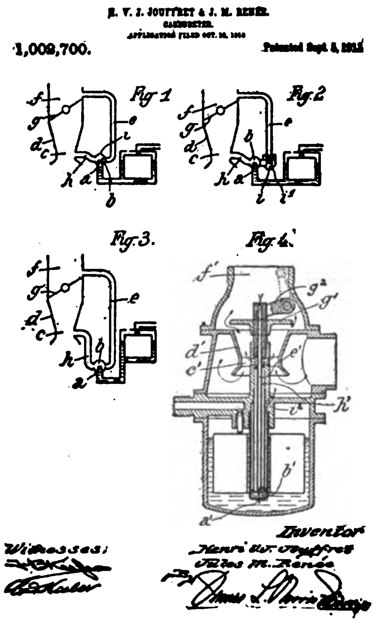
A. J. SCAIFE.
CARBURETER.
APPLICATION FILED DEC. 12, 1910.

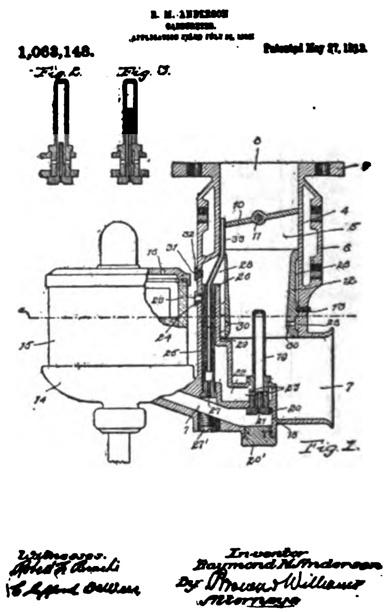
998,123. Patented July 18, 1911.
2 SHEETS—SHEET 2.




A. J. SCAIFE.
Fig. 1.
Fig. 2.
Fig. 3.

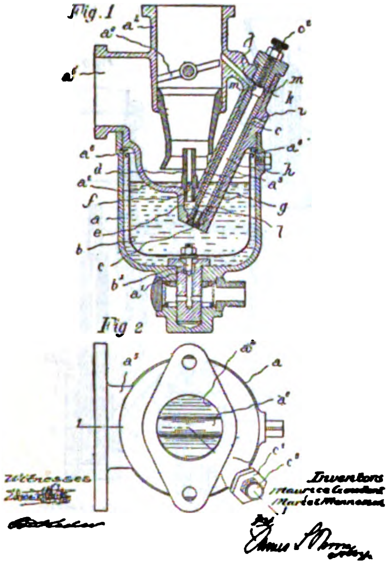

A. J. SCAIFE.
Fig. 4.
Fig. 5.
Fig. 6.
Fig. 7.
Witnesses
Inventor


CARBURETER.
1,009,700.
Fig 1
Fig 2
Fig 3.
Fig 4.
Inventor
Witnesses:


R. M. ANDERSON
CARBURETER.
1,063,148.
Inventor
Raymond M. Anderson

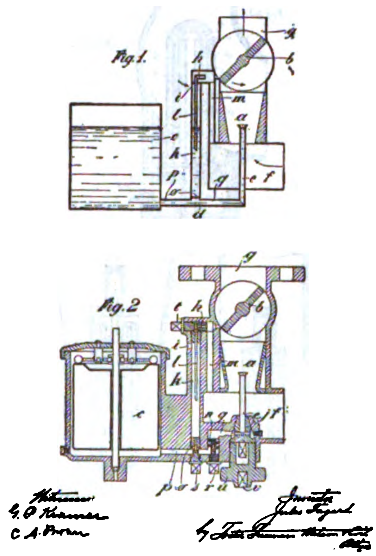
M. GOUDARD & M. MENNESSON.
CARBURETER.
APPLICATION FILED [illegible]

1,090,047. Patented Mar. 10, 1914.



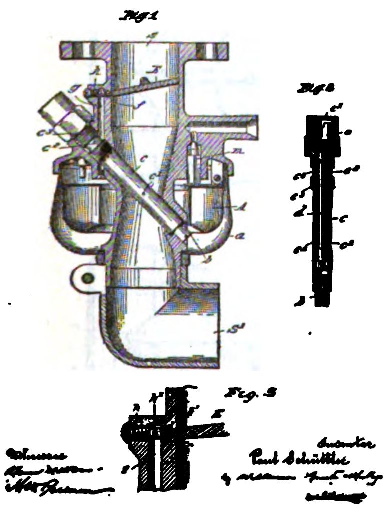
J. FAGERL.
CARBURETER FOR INTERNAL COMBUSTION ENGINES.
APPLICATION FILED [illegible]

1,109,974. Patented Sept. 8, 1914.



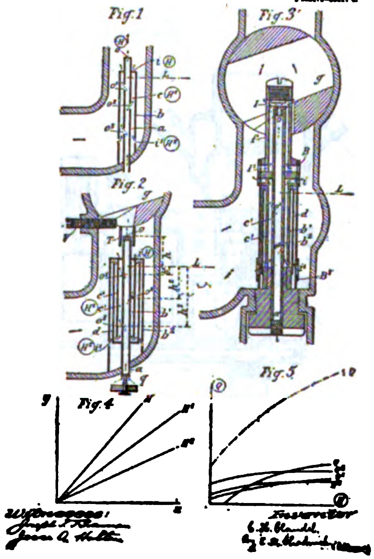
P. SCHÜTTLER.
STARTING AND IDLE RUNNING DEVICE FOR JET CARBURETERS.
APPLICATION FILED JAN. 16, 1914.

1,170,848. Patented Feb. 1, 1916.



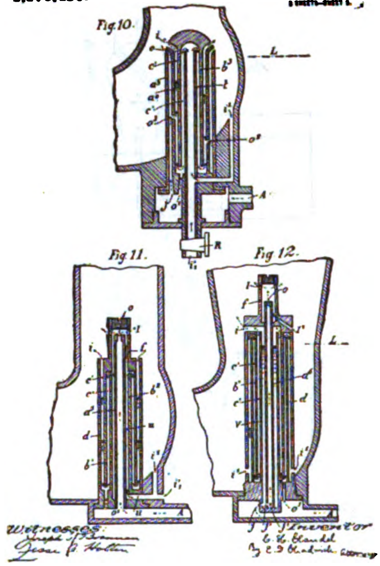
C. H. CLAUDEL.
CARBURETER.
APPLICATION FILED FEB. 6, 1913.

1,170,416. Patented Feb. 1, 1916.
3 SHEETS—SHEET 4.



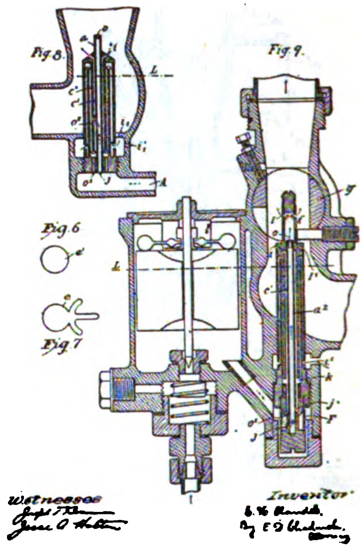
C. H. CLAUDEL.
CARBURETOR.

1,170,416. Patented Feb. 1, 1916.



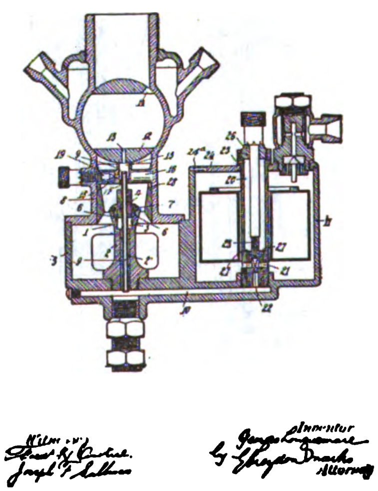
C. H. CLAUDEL.
CARBURETOR.

1,170,416. Patented Feb. 1, 1916.



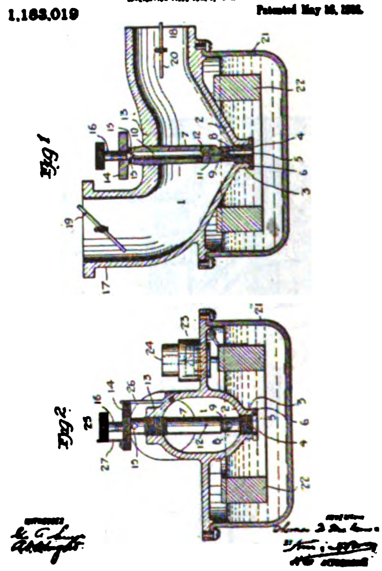
G. LONGUEMARE.
CARBURETER.

1.175,536. Patented Mar. 14, 1916.



T. F. McGUIRE.
CARBURETER.

1,183,019 Patented May 16, 1916.



A. C. BENNETT.
CARBURETER.
APPLICATION FILED JULY 16, 1909.

997,911. Patented July 6, 1909.
2 SHEETS—SHEET 1.

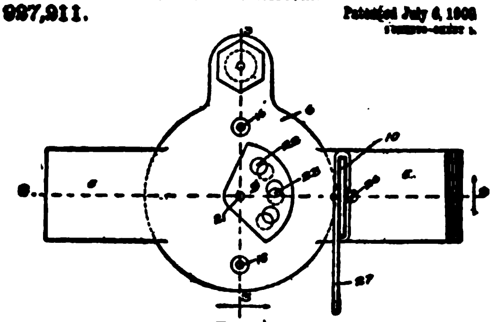


Fig. 1.

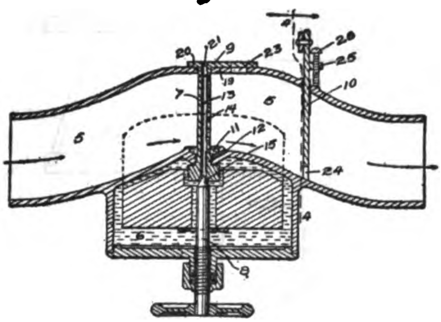


Fig. 2

WITNESSES

INVENTOR.

Ashley C. Bennett

A. C. BENNETT.
CARBURETER.
APPLICATION FILED JULY 10 1907.

927,211. Patented July 6, 1909.
2 SHEETS—SHEET 2.

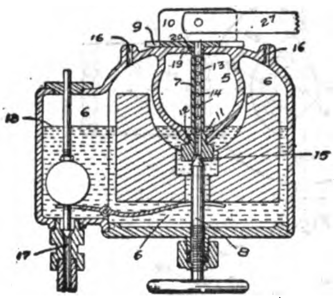


Fig 3.

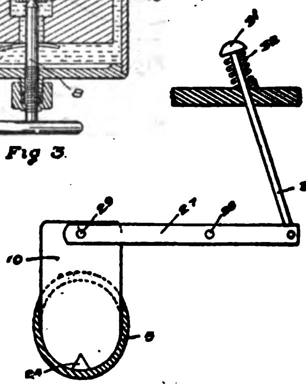


Fig 4

WITNESSES:

INVENTOR
Ashley C Bennett

Class 7—Carburetors, proportioning flow, aspirating, single fixed fuel inlet, single air inlet with regulating valve.—This is the first of the classes in which compensation by changing the flow areas themselves is employed, instead of relying on variations in fuel flow head with fixed passages, or on the number of such fixed inlets brought into action at different flow rates by reason of their location or disposition. In this particular subclass the fuel inlet is single and fixed and the air inlet is varied in such a way as to control the air entrance resistance and its velocity at the fuel inlet, so that the vacuum at that point shall be just sufficient to induce a fuel flow in constant proportion to the air. This vacuum should, of course, be less, other things being equal, than what it would be with a fixed unvarying nonregulated air inlet. Each of the typical groups of forms or means of actuation of the air inlet regulating valve constitutes a subclass, but certain cases overlapping as to subclasses or not directly falling in any one are grouped under the general class heading.

One example of this is the arrangement on page 264 (864,111, Aug. 20, 1907, Sickles), where an externally driven fan draws air through the carburetor and delivers a mixture at a pressure greater than atmosphere, which should yield an increased power output, the air entering through an inlet valve controlled by an outlet throttle, not a primary control for variable speed engines. Another such double featured case is that on page 246 (911,692, Feb. 9, 1909, Andrew), where the air is drawn through a multiported automatic piston valve, passing the fuel inlet by way of an automatically adjusting air throat, which for low rate flows sends all the air across the fuel inlet and for high flow rates by-passes some as a compensation. Another more pronounced automatically variable throat to nozzle relation, with high flow rate by-pass of air previously admitted through a throttle-controlled air valve, is that on pages 264 and 265. (935,833, Oct. 5, 1909, Bassford.) A sort of combination of automatic air inlet and one that is throttle controlled is that on page 265 (1,062,688, May 27, 1913, Bastian), where the air enters through an automatic valve resisted by the throttle cam, and another such is that on page 265 (1,101,736, June 30, 1914, Gillett), having an automatic swing type of valve within the body of a plug valve that is a combined throttle and throttle-controlled air inlet, the automatic controlling the direction of the air that has entered, and its velocity at the fuel inlet.

Subclass 7.1—Fuel inlet between throttle-controlled air valve and throttle.—The direct object of this plan is adjustment of air-entrance resistance so that the vacuum at the fuel inlet shall be maintained proper for constantly proportionate flow, a simple and practical sort of adjustment but not appropriately connected to a throttle for variable speed engines because of the complete lack of dependence of flow rate on throttle position in this case, however much closer the relation may be for engines of the constant-speed class.

On page 266 (771,492, Oct. 4, 1904, Parmenter), a fuel inlet—in fact, a pair of them—is located between a pair of damper valves locked together, one acting as air inlet and the other as throttle, the linkage being adjustable to control to a limited degree their relative rate of movement, which must be properly graduated. On page 267 (789,749, May 16, 1905, Maxwell), the plug valve, with one edge acting as air valve and the other as throttle, has the inlet in the

middle between them, an arrangement that limits the adjustment and graduation of relative movement. A cylindrical chamber with an adjustable air inlet in one end and a slot in its side acts by rotation as both air valve and throttle, the fuel inlet being between, as shown on page 267. (794,927, July 18, 1905, Cashman & Cushman.) A sliding air valve linked to a damper throttle, pages 267 and 268 (932,465, Aug. 31, 1909, Haas), is fitted with a hollow-stem needle-valved fuel inlet between them, the hollow stem acting as a lifting tube for low-flow rates as its upper end communicates with a passage above the throttle. Another such lifting tube with an accelerating cup is shown in the combined air inlet and throttle plug type on page 268 (1,006,387, Oct. 17, 1911, Kreis, jr.)

A slide valve, acting as throttle and air valve, is shown on page 269 (1,062,333, May 20, 1913, Higgins), the relative adjustment of their two areas being accomplished by varying the lateral width of one port of the air inlet and using another port unmodified, which closes as the adjusted one opens under the longitudinal movement of the slide as it closes the throttle. A great variety of such linkages is found, showing a more or less keen appreciation of the importance of the proper relative adjustment with reference to the throttle, both for slide valves, balanced piston and poppet valves, and dampers of all sorts, some of them involving the use of cams. In the form page 269 (1,095,101, Apr. 28, 1914, Gardner) a pair of cam grooves cause a disk air valve and a similar throttle to move axially in opposite directions with reference to a tapered air throat, around which a series of fuel inlets is disposed. One of the most recent of these cases applies the pair of linked dampers of figure 140 to a triple inlet—one for gasoline, one for kerosene, and one for water, similarly disposed and each with its own level chamber, as shown on page 270. (1,150,202, Aug. 17, 1915, Johnston & Longenecker.) The use of a double-tapered sleeve, with two contractions moving in a cylindrical shell past a solid plug, and a central fuel-inlet plug, as combined air inlet and throttle, is shown on page 270 (1,151,286, Aug. 24, 1915, Rowell), the relative area changes being accomplished by the shape angle or curvature of the tapers of the two plugs with reference to their matching annular sleeves.

Subclass 72—fuel inlet at or before air valve which acts as throttle.—Placing the fuel inlet jet at or before the air inlet orifice relieves it of practically all the vacuum due to entrance resistance, and makes fuel flow depend solely, or substantially so, on variations of air velocity past it, as such velocity produces a pressure depression equivalent to the air velocity head. In such a case the air valve is itself the throttle. Of course air velocity has no prime relation to the throttle or air valve opening except for constant speed engines, so as in other cases where the throttle is the means of actuating whatever air or fuel regulating valves may be used, the application is of lesser if of any value whatever, to variable-speed engines. A balanced form of air valve, acting as throttle and so formed as to keep the air flow concentrated past the fuel nozzle which is located in front in a region of practically no vacuum except that due to air velocity, is shown on page 271. (815,712, Mar. 20, 1906, Johnston.) The valve is a piston with a tapered central hole in which the nozzle stands, and with radial ports throughout its length. It moves in a

cylindrical partition between the air supply and the mixing chamber. It keeps the air flow moving across the jet, at first almost entirely radially and later part radially and part longitudinally. In the form, page 271 (816,846, Apr. 3, 1906, Charron & Girardot), the fuel inlet is located just below the plane of action of an iris throttle, similar to the photographic shutter. A pair of oppositely moving slides with the fuel valve located midway in their plane of action is shown on page 272. (868,251, Oct. 15, 1907, Bollee.) A single damper, arranged with a fuel inlet at one side of the passage, is made to serve as on page 273 (1,080,118, Dec. 2, 1913, Monosmith), and the same thing with the damper bent and used with one water and one fuel inlet differently situated so the fuel flow has a lead on that of the water, is shown on page 273. (1,108,181, Aug. 25, 1914, Kane.) Use of a helical spring, the coils of which may touch or on extension be drawn apart, is used as both air inlet and throttle valve, as shown on page 274 (1,117,233, Nov. 17, 1914, Parker), the fuel inlet being inside the coil, and the lower portion serving as air inlet and the upper part as throttle. A pair of cams geared together with the fuel inlet midway is shown on page 274. (1,143,227, June 15, 1915, Prescott.)

Subclass 7.3—Fuel inlet between automatic air valve and throttle.—Air entering through an automatic air valve will not produce as great an increase in entrance resistance or in static mixing chamber vacuum with increase of flow as if it entered through a fixed inlet, and this not only tends to produce a higher density of charge than is otherwise possible but it may be used as a means of compensation for correcting proportions. Of course, velocity head vacuum at the fuel inlet is the same with automatic valved as with fixed inlets, so whatever compensating effect is produced must be through a modification of the entrance resistance. The way in which the entrance resistance varies with flow depends primarily on the form of the automatic valve and on its manner of loading.

A spring-loaded piston type of automatic air inlet is shown on page 275 (759,396, May 10, 1904, Rutenber), the air passing down and impinging on a plate surrounding the fuel inlet and mushrooming sideways, so whatever velocity head vacuum there is will probably be negative, though small, and fuel flow is controlled primarily by the vacuum produced by the valve, which will be determined by the spring and the shape of the ports. On page 275 (794,502, July 11, 1905, Hennebutte), air enters through an annular check-valve spring loaded, passes downward, sweeping at the bottom a two-ported fuel inlet on which it exerts some positive velocity head effect, and a hand-adjusted by-pass permits this to be least manually controlled. Mixing baffles are also employed beyond the jet. A swing check-valve spring loaded is illustrated on page 275 (796,723, Aug. 8, 1905, Hewitt), with the fuel inlet in the center of a straight cylindrical chamber. A similar spring-loaded swing check that does not completely close the inlet and therefore exerts no entrance resistance at very low flow rates is shown on pages 275 and 276. (806,434, Dec. 5, 1905, Schebler.) The air flows downward to a bend into which the fuel nozzle projects, the air velocity head acting negatively but uncertainly because of the eddy currents and initial direction given to the air by the spring valve. Another swing check, itself a spring, and

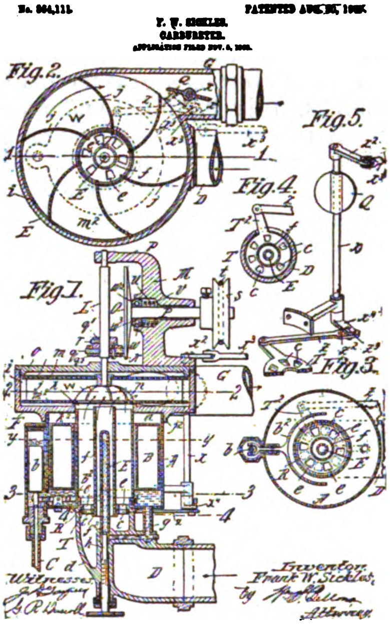
arranged in a straight passage to deflect the air away from the fuel inlet at first and then as flow increases allowing the air to sweep the fuel inlet, is shown on page 276 (831,547, Sept. 25, 1906, Dunlop & Dunlop), so that at low-flow rates the vacuum is all due to entrance resistance, but at high rate, as this increases but little with such a valve, the air velocity head vacuum is brought into action to induce sufficient flow. Another attempt to secure velocity head control by form is shown on page 276 (947,712, Jan. 25, 1910, Henricks), which places the jet in a bend supplied with air through a spring check with a fixed by-pass. Four fuel inlets, similarly placed and swept by the air from a single spring air check, are shown on page 277 (986,700, Mar. 14, 1911, Fogel), the four acting, so far as proportionality is concerned, no differently than one. While designed primarily to operate on compressed air, the form shown on page 278 (1,039,229, Sept. 24, 1912, Walker) is especially well adapted to air at atmospheric pressure and will have the same proportionality characteristics with reference to flow, whatever the air pressure, except, of course, as density changes may enter as variables. The supply air acting directly on the free fuel surface before passing the spring-loaded air valve produces a differential pressure that will result in fuel flow even without the location of the jet in an air throat as shown. Of course, this arrangement naturally tends toward enrichment. A graduated series of five annular air checks is shown on page 276 (1,124,918, Jan. 12, 1915, Krause) to build up sufficient vacuum with flow increase to secure correct proportioning at at least as many points as there are rings for steady flow.

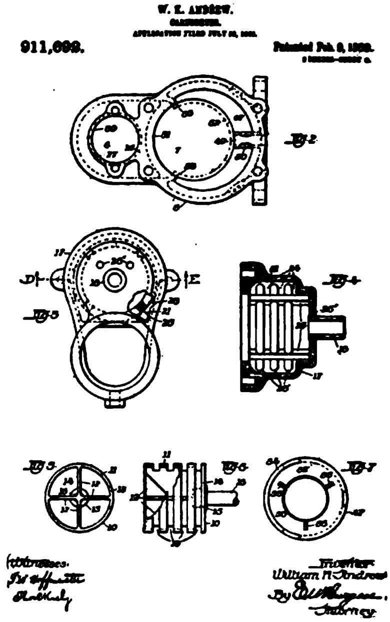
Subclass 7.4—fuel inlet swept by air entering through automatic valve.—Unless the seating resistance of automatic air inlet valves increases with the flow rate as they open, the entrance resistance will not produce a sufficient vacuum at the fuel inlet to draw in a proportionate amount of fuel, and in such cases there must be a resort to velocity head assistance. Therefore, when the fuel inlet is beyond the automatic air valve there must be a properly graduated increasing air valve seating load or a graduated air velocity head action at the jet or both. If the fuel inlet be located in the opening of the automatic air valve so as to get only velocity head vacuum and no entrance resistance vacuum, then as a fixed opening builds up vacuum too fast for proportionate fuel flow, a yielding automatic valve may be a proper compensator, but it likewise must have a variable load because otherwise the velocity would not increase at all as the opening and the flow increased. Therefore the question of location of the fuel inlet with reference to the entering air stream is intimately bound up with that of automatic air valve loading, and the cases of this subclass are concerned primarily with locations of fuel inlet that will be swept by the entering air and be influenced by its velocity head to a considerable degree, being correspondingly less dependent on the valve loading alone.

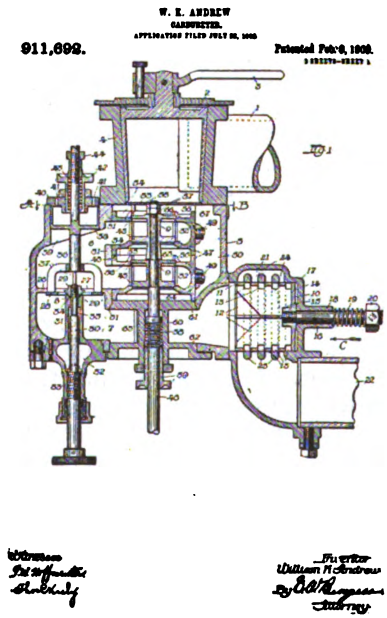
On page 279 (783,902, Feb. 28, 1905, Shipman) the automatic valve is a spring loaded check form, directing all the air across the fuel inlet which receives none of the entrance resistance vacuum, being located constantly at the variable throat of a rectangular venturi. A precisely similar effect in a round annular venturi is pro-

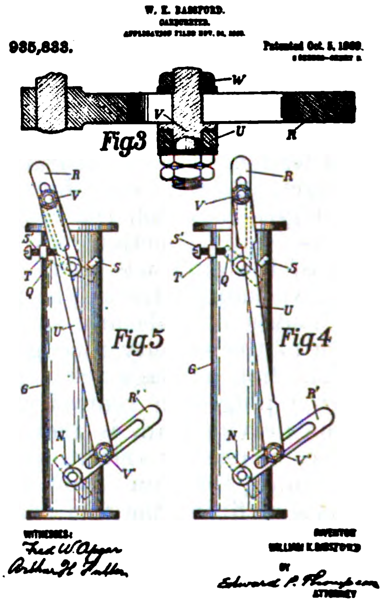
duced by the spring loaded core acting as an air valve, but not seating tight, on page 279. (799,232, Sept. 12, 1905, Gosse.) A series of swing checks are used on pages 279 and 280 (800,647, Oct. 3, 1905, Hatcher), the fuel inlet being inside when the valves are closed and at the throat or outside of it when they are open. A fixed circular row of fuel inlets is located within a lifting ring, acting as a gravity loaded automatic air valve on page 280 (859,719, July 9, 1907, Anderson), and always outside as soon as the valve lifts. Quite the same arrangement, but with a spring loaded annular air valve is shown on page 280. (875,716, Jan. 7, 1908, Longuemare.) Two air streams acting as one, one fixed and the other entering through an annular gravity loaded automatic valve, are both directed by walls across the jet, which is slightly inside, on page 280. (916,103, Mar. 23, 1909, Cartwright.) A long taper check valve in a similar long taper seat rises very steadily with flow increase and keeps a substantially constant vacuum, as shown on page 281. (924,200, June 8, 1909, Stewart.) A spring loaded piston operated gate valve is shown on page 282 (928,-828, July 20, 1909, Winton), working across the air passage in the plane of the fuel inlet which is therefore always at the most restricted and highest velocity point. The vacuum above the throttle is used to depress or close the valve. A peculiar form of swing check directing part of the air toward the jet and part around it as it opens is illustrated on page 283. (973,877, Oct. 25, 1910, Pierce.)

In figure 174 (1,000,398, Aug. 15, 1911, Gentle) the spring-loaded check lifts the fuel inlet past a baffle to keep it always in the high velocity current, and a second swinging mixture check helps to control the direction. A somewhat similar idea underlies the different construction on page 283 (1,042,982, Oct. 29, 1912, Sliger), where a fixed central air jet is also an automatic spring-loaded air valve, both streams being directed across the fuel inlet. Use of fuel inlets in the walls of a venturi throat with a tapered central plug, tending to keep the throat velocity constant, is shown on page 283 (1,052,051, Feb. 4, 1913, Grimes), as a means of compensation for the enrichment tendency that is natural for such free throats where the velocity regularly increases with flow. Of course, the satisfaction depends on the degree to which the compensation can be carried even though qualitatively the action may be in the right direction. The spring load of the plug acts counter to gravity. A pair of cam-operated gates, vacuum controlled, keeps the jet always in the entering stream and makes possible any sort of rate control on the opening, and hence of the velocity through it as flow increases, according to the construction on page 284 (1,093,901, Apr. 21, 1914, Wyman), of a tapered plug in a venturi throat, with a light spring load added to the gravity lead, is arranged to concentrate the air flow at, of course, increasing velocities with flow increases, across an annular feed inlet, the flow from which must follow the capillary law, because of filling the fuel passage with fibrous material in the form shown on page 285. (1,140,000, May 18, 1915, Rubetsky.) This is an example of the effort to control the fuel-flow law, while imposing a flow vacuum varying with flow in a manner prescribed by the other structural arrangements and dimensions. Comparatively recent form of moving venturi throat, acting as an automatic air inlet gravity loaded, is shown on page 286 (1,148,247, July 27, 1915, Moore), and

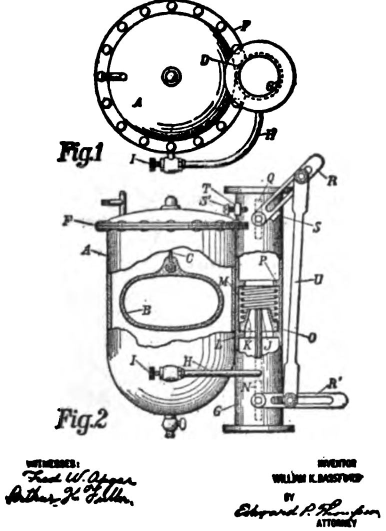

F. W. SICKLES.
CARBURETER.
Fig.2.
Fig.5.
Fig.4.
Fig.1.
Fig.3.
Witnesses
Inventor
Frank W. Sickles,
Attorney


W. K. ANDREW.
911,699.
Witnesses.
Inventor
William K. Andrew
Attorney

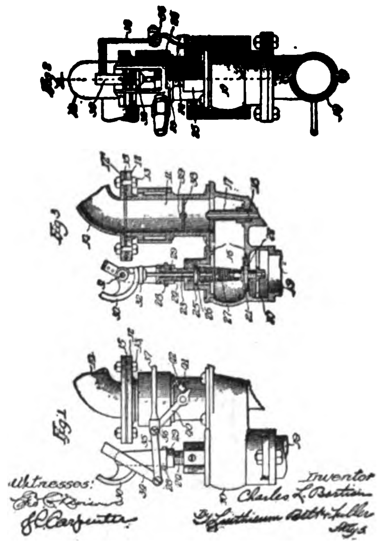

W. K. ANDREW
CARBURETER.
911,692.
Witnesses
Inventor
William K. Andrew
Attorney


W. K. BASHFORD.
CARBURETER.
935,833.
Fig3
Fig.5
Fig.4
WITNESSES:
Fred W. Apgar
Arthur H. Fuller
INVENTOR
WILLIAM K. BASHFORD
BY
Edward P. Thompson
ATTORNEY

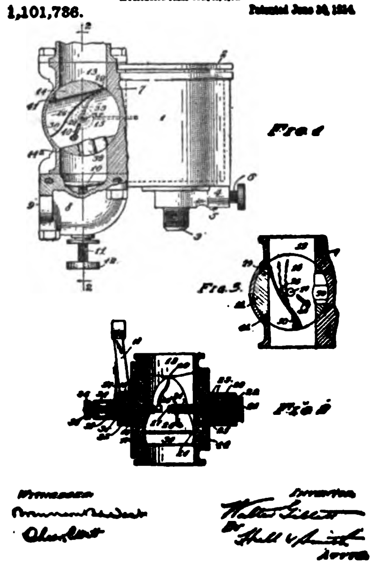
W. K. BASSFORD.
CARBURETER.
935,833. Patented Oct. 5, 1909.



C. L. BASTIAN.
CARBURETER.
1,062,838. Patented May 27, 1913.



W. GILLETT.
CARBURETER.
1,101,786. Patented June 30, 1914.



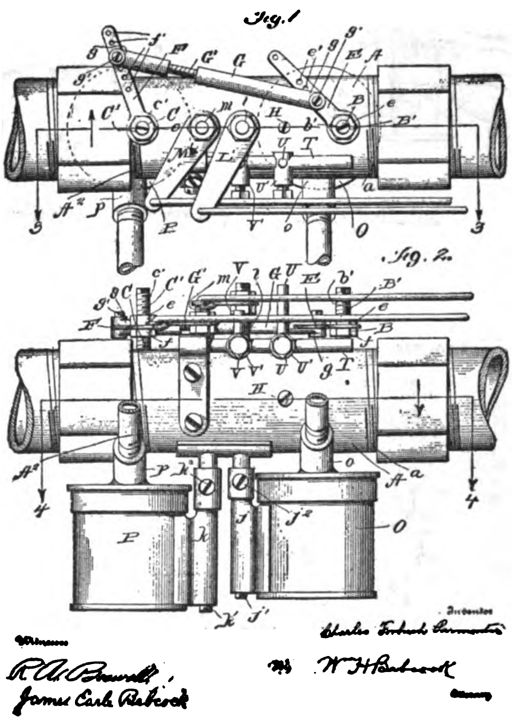
No. 771,462. PATENTED OCT. 4, 1904.

C. F. PARMENTER.

CARBURETER FOR EXPLOSIVE ENGINES.

APPLICATION FILED MAR. 12, 1904.

NO MODEL. 2 SHEETS—SHEET 1.



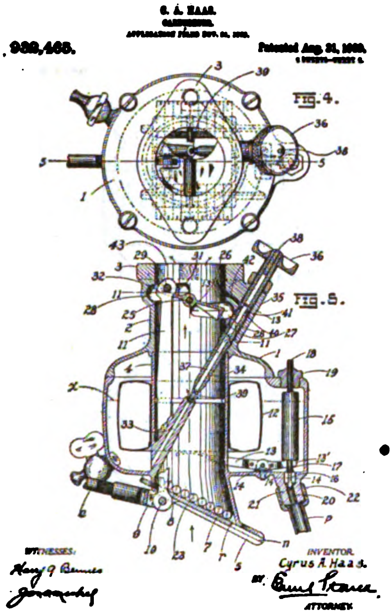
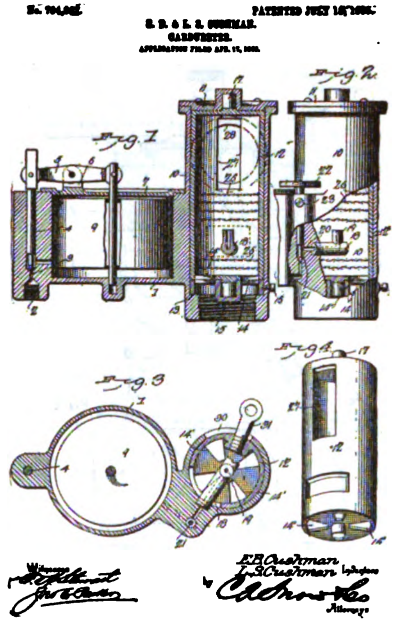
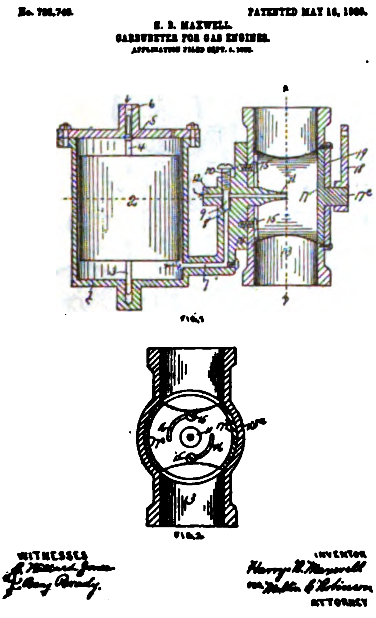


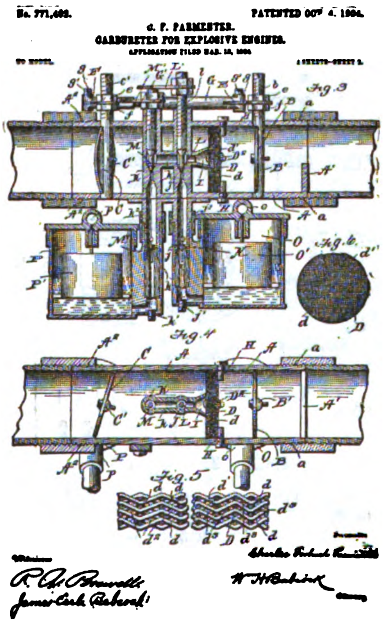
Fig. 4.
Fig. 5.
WITNESSES:
INVENTOR
Cyrus A. Haas.
ATTORNEY



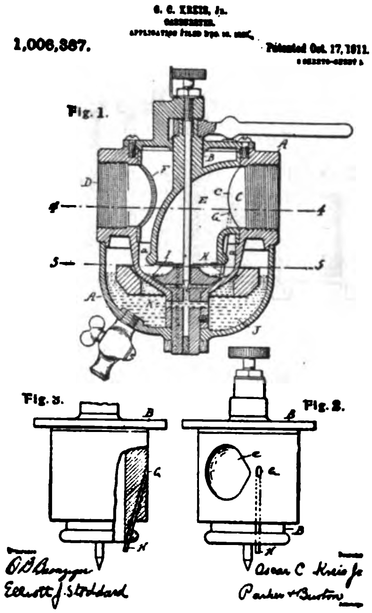
CARBURETER.
Fig. 1
Fig. 2
Fig. 3
Fig. 4
Attorneys

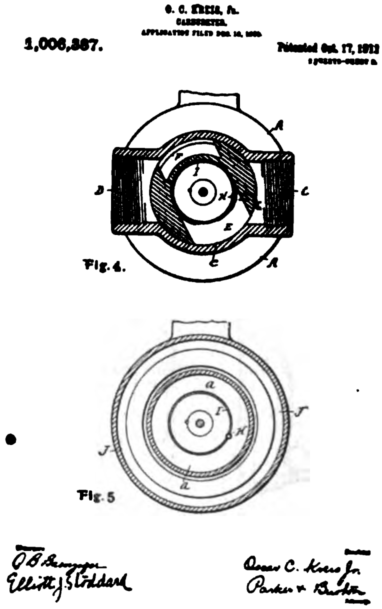


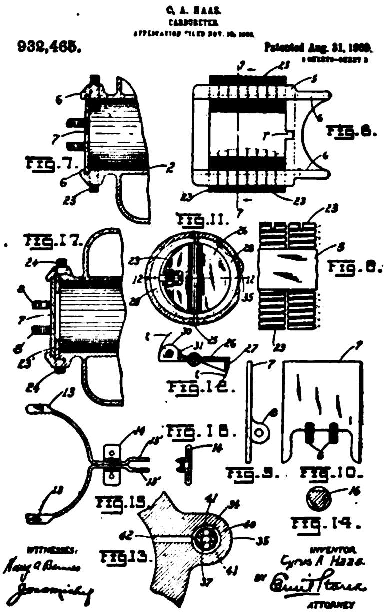
CARBURETER FOR GAS ENGINES.
FIG. 1
FIG. 2
WITNESSES
INVENTOR
ATTORNEY

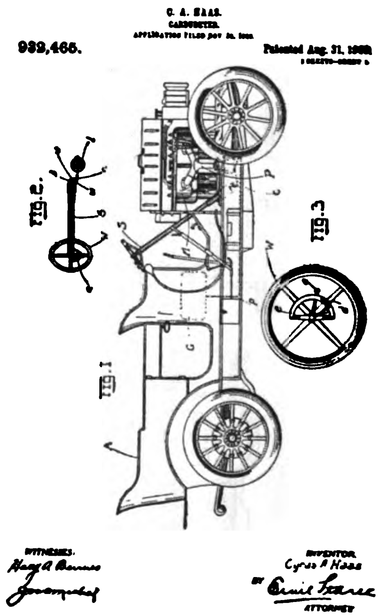


CARBURETER FOR EXPLOSIVE ENGINES.
Fig. 3
Fig. 4
Fig. 5
Fig. 6

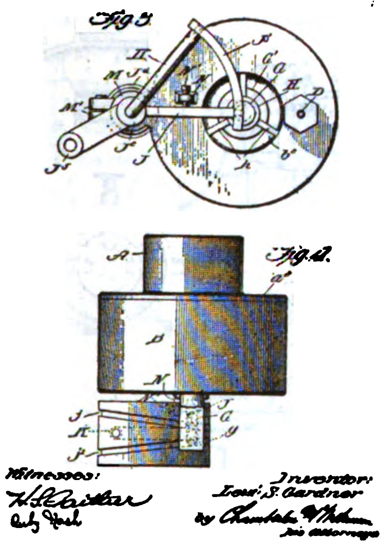

O. C. KREIS, Jr.
CARBURETER.
1,006,387.
Patented Oct. 17, 1911.
Fig. 1.
Fig. 3.
Fig. 2.
Oscar C. Kreis Jr.
Parker + Burton
Elliott J. Stoddard


O. C. KREIS, Jr.
CARBURETER.
1,006,387.
Patented Oct. 17, 1911.
Fig. 4.
Fig. 5
Oscar C. Kreis Jr.
Parker + Burton
Elliott J. Stoddard

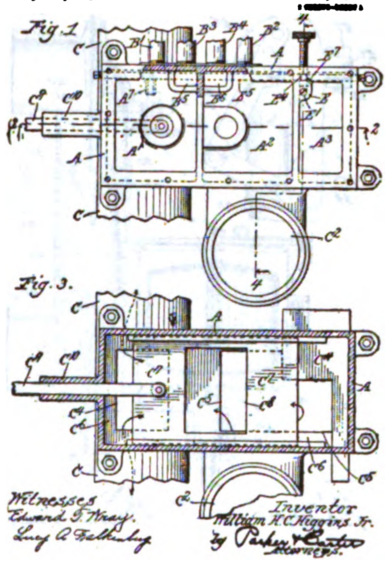

C. A. HAAS.
CARBURETER.
932,465.
Patented Aug. 31, 1909.
FIG. 7.
FIG. 6.
FIG. 11.
FIG. 17.
FIG. 8.
FIG. 12.
FIG. 16.
FIG. 9.
FIG. 10.
FIG. 15.
FIG. 14.
FIG. 13.
WITNESSES:
INVENTOR
Cyrus A Haas
BY
ATTORNEY


C. A. HAAS.
CARBURETER.
932,465.
Patented Aug. 31, 1909.
FIG. 2.
FIG. 3
FIG. 1
WITNESSES:
INVENTOR
Cyrus A Haas
BY
ATTORNEY

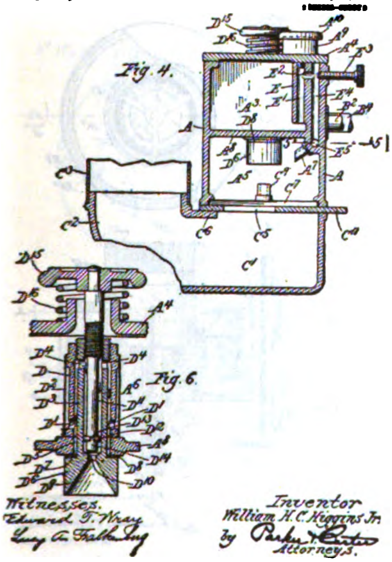
L. S. GARDNER.
CARBURETER.
1,095,101. Patented Apr. 28, 1914.



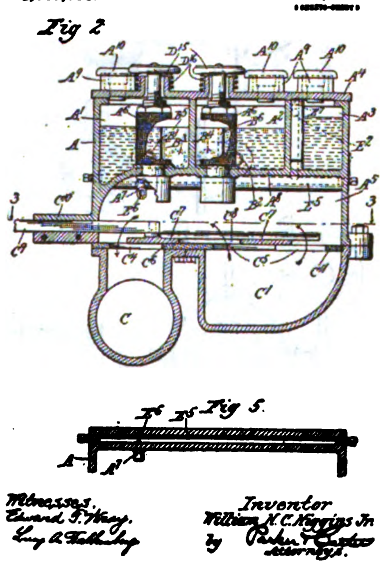
W. H. C. HIGGINS, Jr.
CARBURETER.
APPLICATION FILED JULY 5, 1910.
1,062,333. Patented May 20, 1913.



W. H. C. HIGGINS, Jr.
CARBURETER.
APPLICATION FILED JULY 5, 1910.
1,062,333. Patented May 20, 1913.



W. H. C. HIGGINS, Jr.
CARBURETER.
APPLICATION FILED JULY 5, 1910.
1,062,333. Patented May 20, 1913.



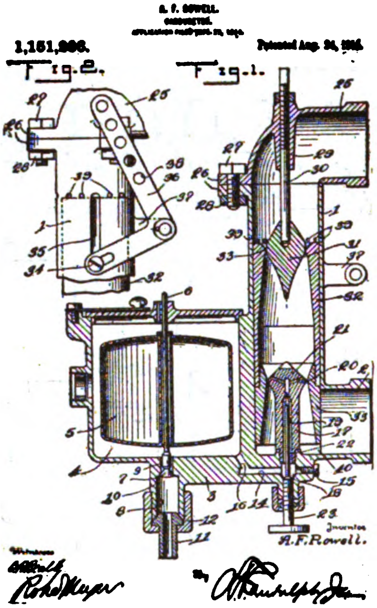
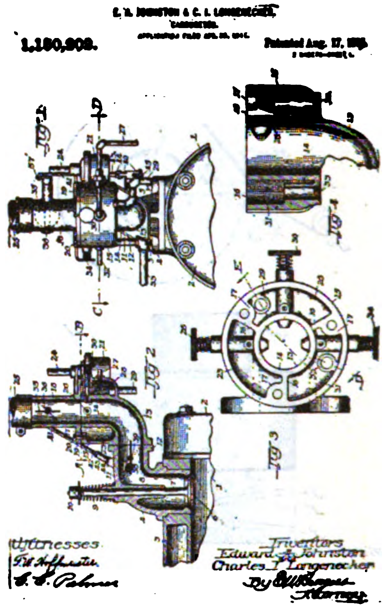
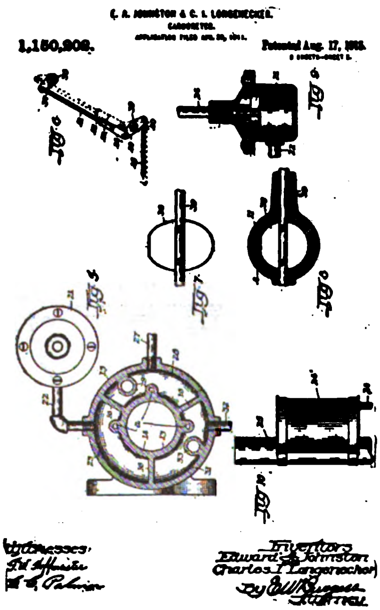


Fig. 2.
Fig. 1.
A.F.Rowell.


Witnesses
Inventors
Edward A. Johnston
Charles I. Longenecker


Witnesses
Inventors
Edward A. Johnston
Charles I. Longenecker

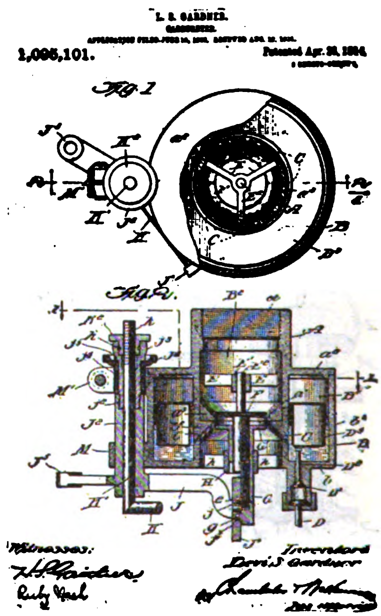


Fig. 1
Fig. 2.
Witnesses:
Inventor

No. [illegible]

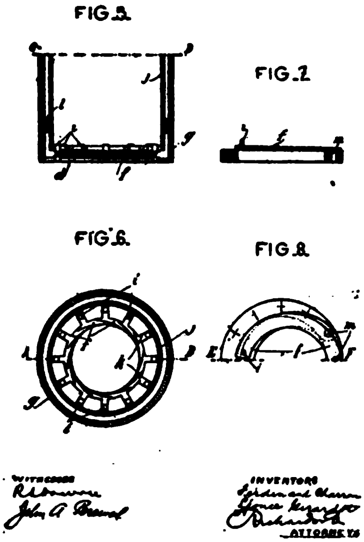
PATENTED APR. 3, 1906.

F. CHARRON & L. GIRARDOT.

CARBURETER FOR PETROLEUM MOTORS.

APPLICATION FILED MAR. [illegible] 1905.

[illegible] SHEETS—SHEET 1.



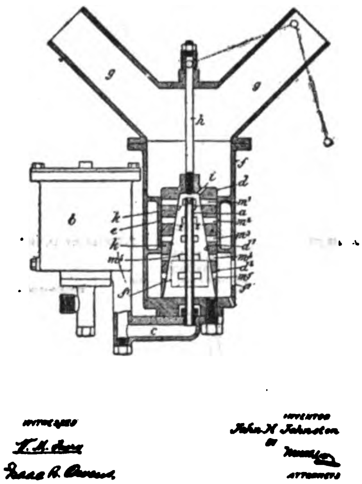
No. [illegible]

PATENTED MAR. 20, 1906.

J. H. JOHNSTON.

CARBURETER FOR EXPLOSIVE ENGINES.

APPLICATION FILED [illegible]



No. [illegible]

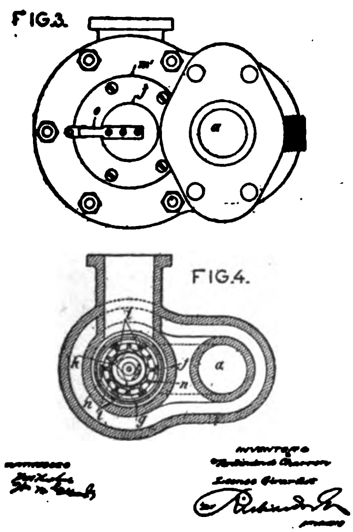
PATENTED APR. 3, 1906.

F. CHARRON & L. GIRARDOT.

CARBURETER FOR PETROLEUM MOTORS.

APPLICATION FILED MAR. [illegible] 1905.

[illegible] SHEETS—SHEET 2.



No. [illegible]

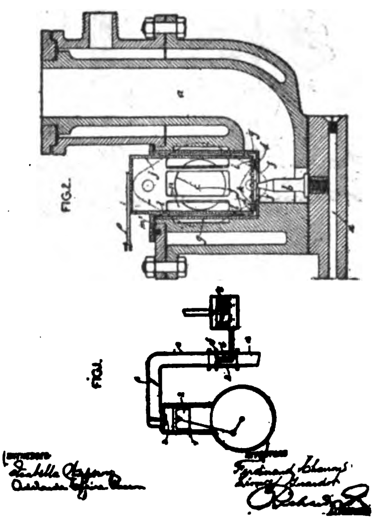
PATENTED APR. 3, 1906.

F. CHARRON & L. GIRARDOT.

CARBURETER FOR PETROLEUM MOTORS.

APPLICATION FILED MAR. [illegible] 1905.

[illegible] SHEETS—SHEET 1.



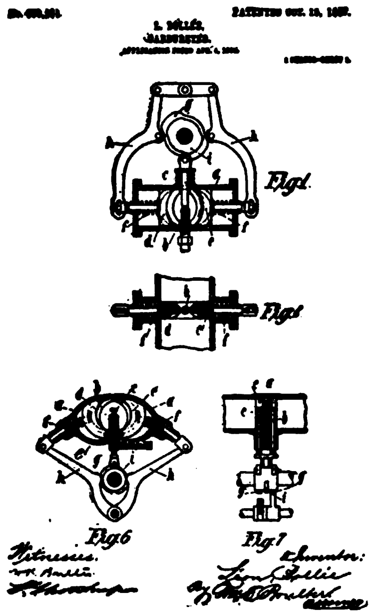


Fig. 1.
Fig. 6
Fig. 7
Witnesses.
Inventor:

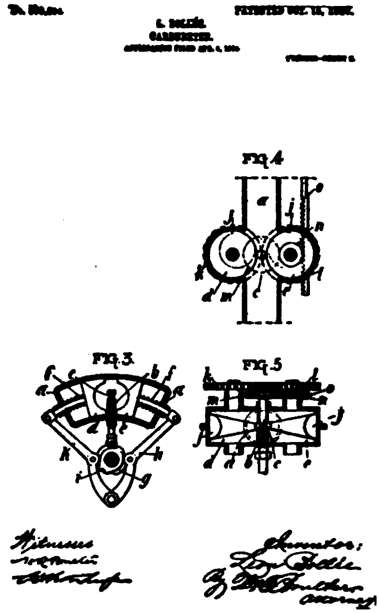
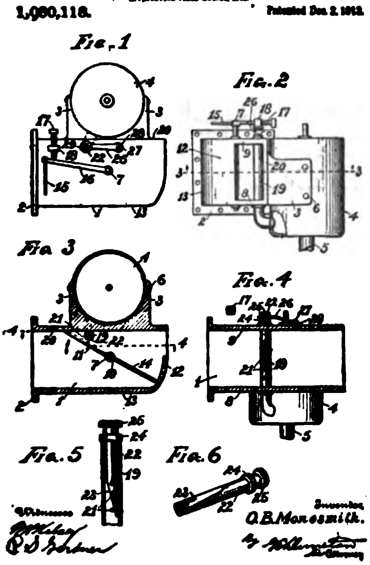


FIG. 4
FIG. 3
FIG. 5
Witnesses
Inventor:

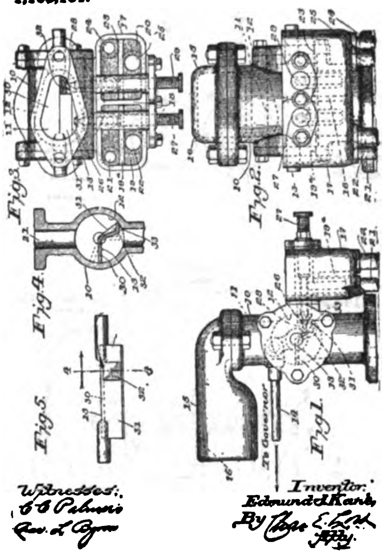
O. B. MONOSMITH.
CARBURETER.
APPLICATION FILED AUG. 26, 1912.

1,080,118. Patented Dec. 2, 1913.



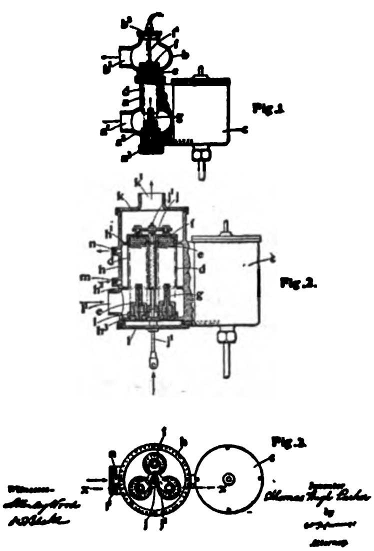
E. J. KANE.
CARBURETER.
APPLICATION FILED JUNE 20, 1912.

1,108,181. Patented Aug. 25, 1914.



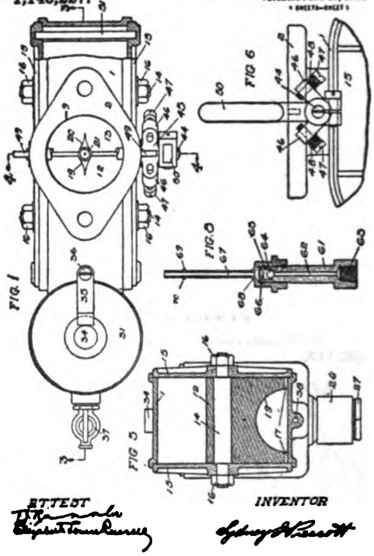
T. H. PARKER.
CARBURETER.
APPLICATION FILED AUG. 19, 1913.

1,117,838. Patented Nov. 17, 1914.



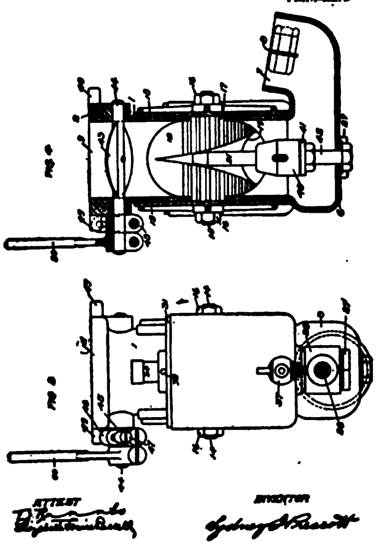
S. L. PRESCOTT.
CARBURETER.
APPLICATION FILED DEC. 1, 1909.

1,143,227. Patented June 15, 1915.
3 SHEETS—SHEET 1.



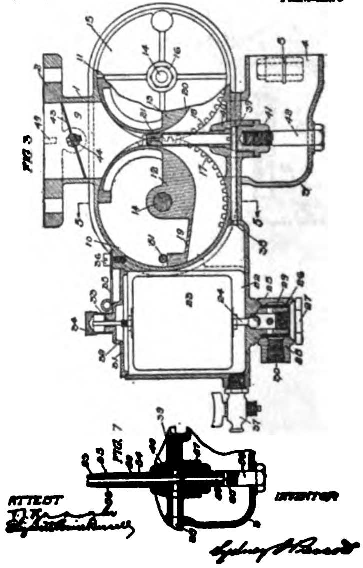
S. L. PRESCOTT.
CARBURETER.
APPLICATION FILED DEC. 1, 1909.

1,143,227. Patented June 15, 1915.
3 SHEETS—SHEET 2.



S. L. PRESCOTT.
CARBURETER.
APPLICATION FILED DEC. 1, 1909.

1,143,227. Patented June 15, 1915.
3 SHEETS—SHEET 3.

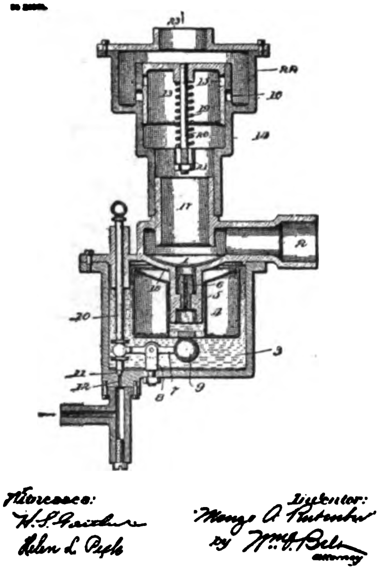


No. [illegible] PATENTED MAY [illegible], 1904.

M. A. RUTENBER.

CARBURETER FOR HYDROCARBON ENGINES.

APPLICATION FILED [illegible]

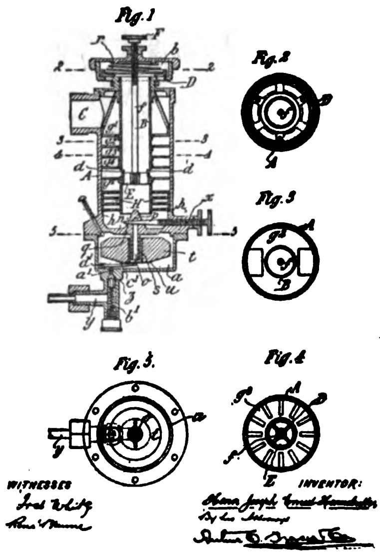


No. [illegible] PATENTED JULY 11, 1905.

H. J. E. HENNEBUTTE.

CARBURETER.

APPLICATION FILED [illegible]

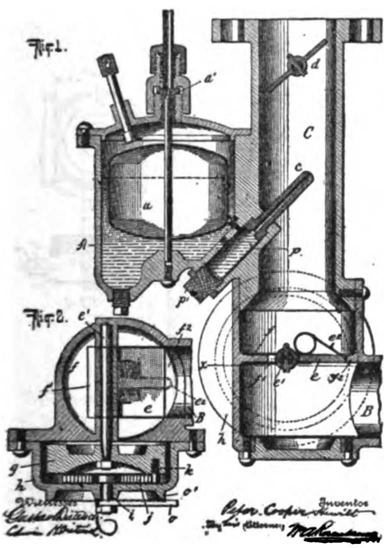


No. [illegible] PATENTED AUG. 8, 1905.

P. C. HEWITT.

CARBURETER.

APPLICATION FILED APR. [illegible]

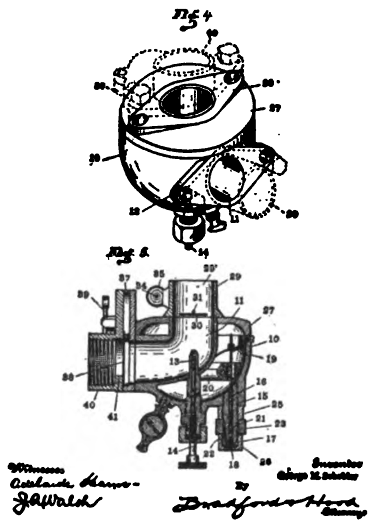


No. [illegible] PATENTED DEC. 8, 1908.

G. M. SCHEBLER.

CARBURETER FOR HYDROCARBON MOTORS.

APPLICATION FILED OCT. [illegible]

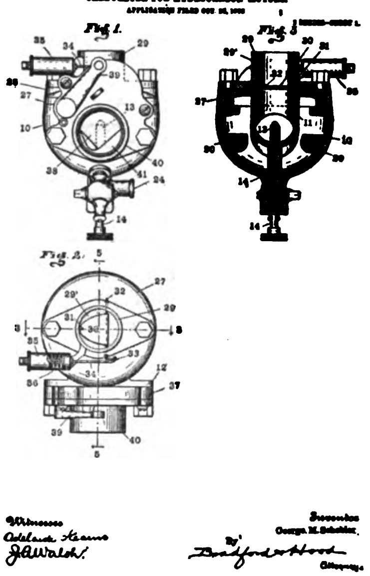


No. [illegible] PATENTED DEC. 6, 1906.

G. M. SCHEBLER.

CARBURETER FOR HYDROCARBON MOTORS.

APPLICATION FILED OCT. [illegible]

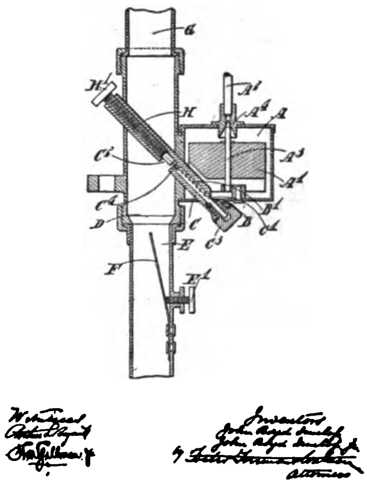


No. [illegible] PATENTED SEPT. [illegible]

J. B. DUNLOP & J. B. DUNLOP, Jr.

CARBURETER FOR EXPLOSIVE ENGINES.

APPLICATION FILED JUNE [illegible]

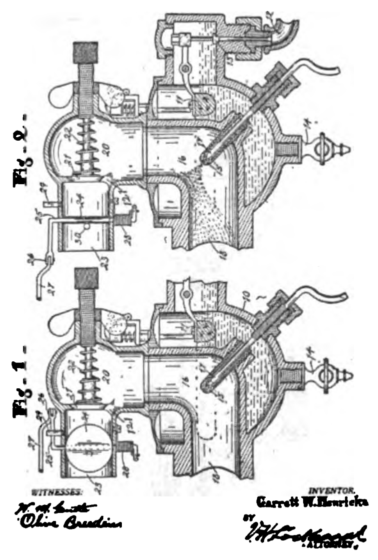


G. W. HENRICKS.

CARBURETER.

APPLICATION FILED JAN. [illegible]

947,712. Patented Jan. 25, 1910.

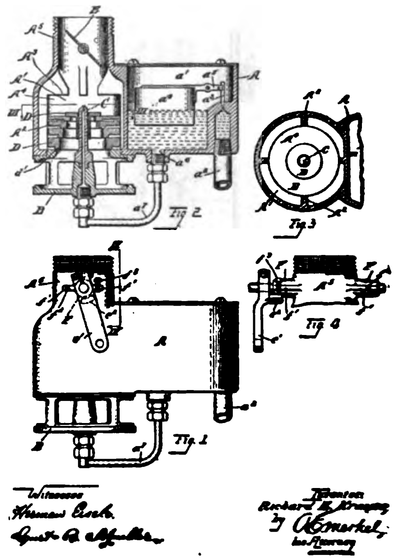


R. E. KRAUSE.

CARBURETER.

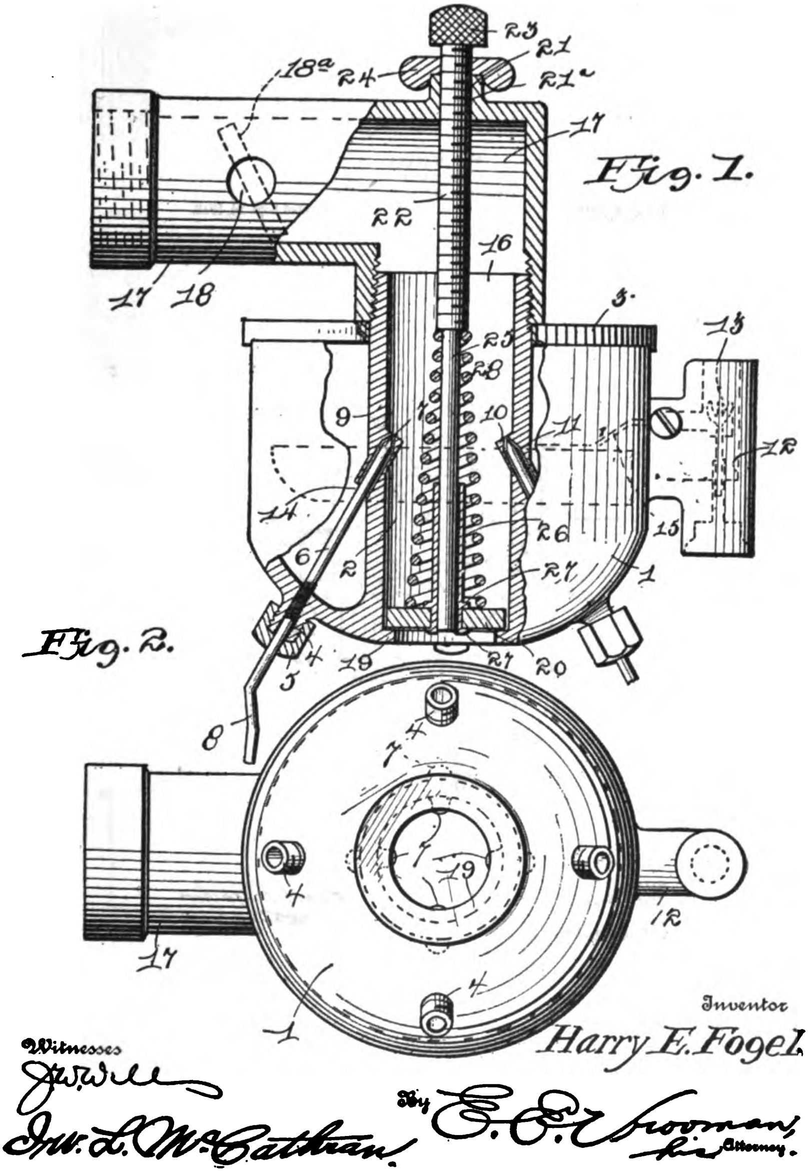
APPLICATION FILED APR. [illegible]

1,124,918. Patented Jan. 12, 1915.



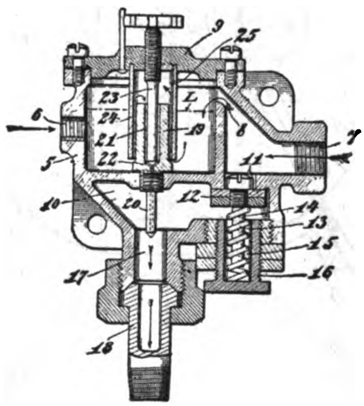
H. E. FOGEL.
CARBURETER.
APPLICATION FILED JULY 31, 1909.

986,700. Patented Mar. 14, 1911.



F. H. WALKER.
CARBURETER.
APPLICATION FILED JULY 27, 1911.

1,039,229. Patented Sept. 24, 1912.



WITNESSES

A. R. Walton

INVENTOR

Frank H. Walker

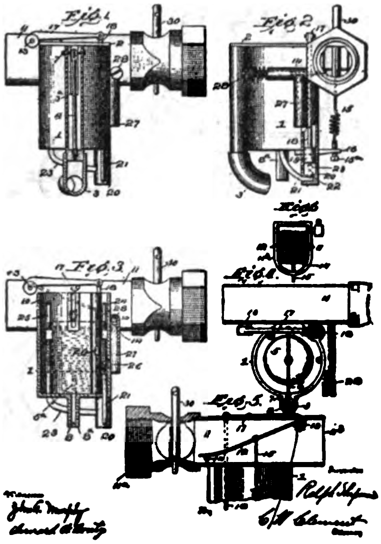
by Milo B. Stevens & Co.

Attorneys

PATENTED FEB. 20, 1906.

R. SHIPMAN.

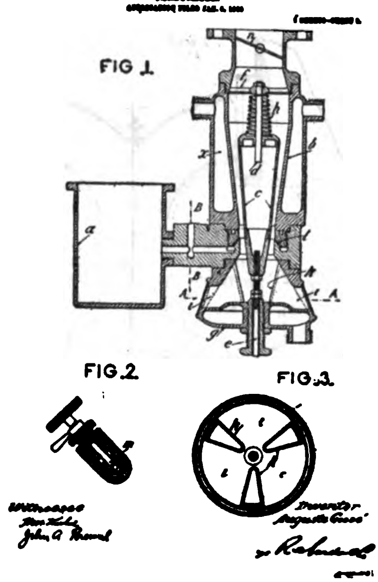
CARBURETER FOR EXPLOSIVE ENGINES.



PATENTED SEPT. 12, 1905.

A. GOSSÉ.

CARBURETER.



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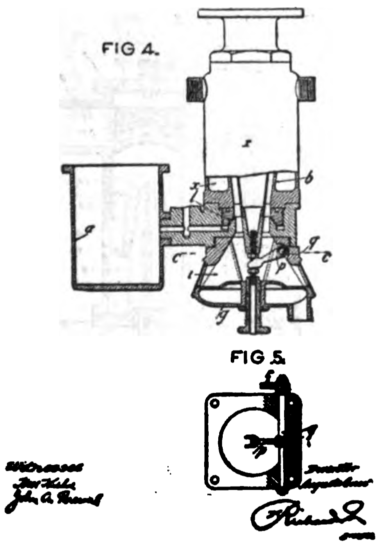
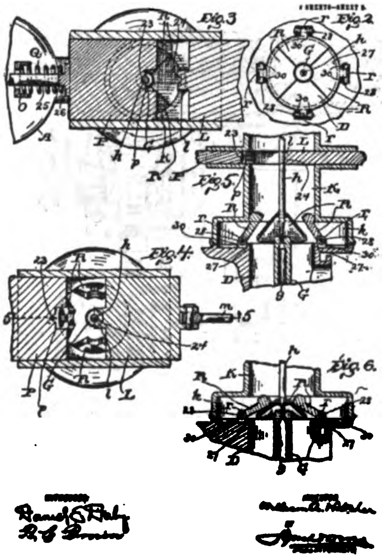
A. GOSSÉ.

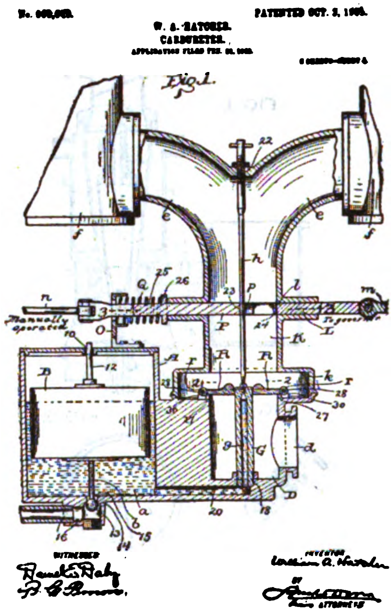
CARBURETER.

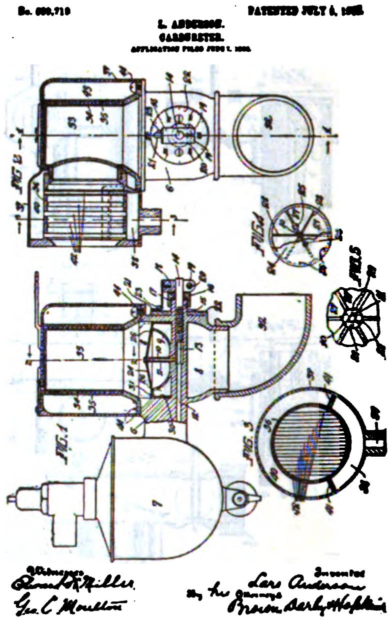


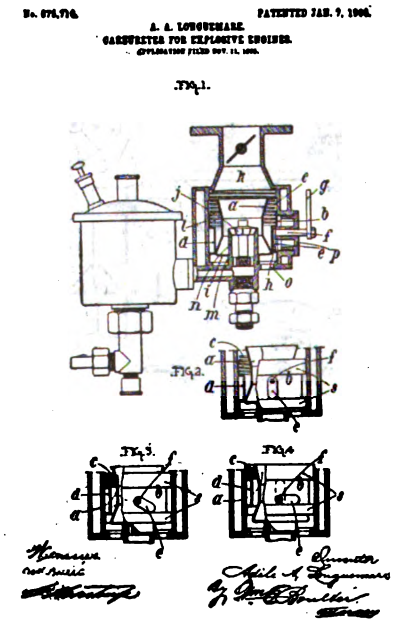
W. A. HATCHER.

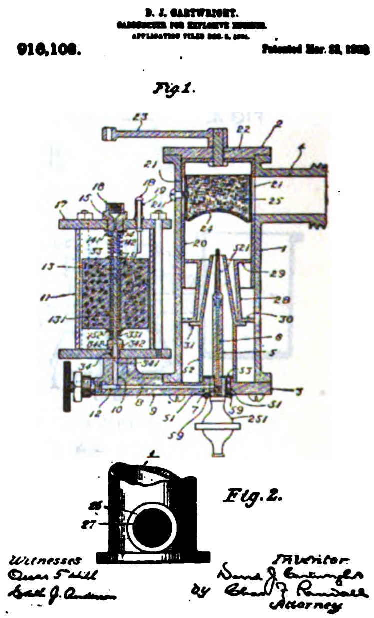
CARBURETER.



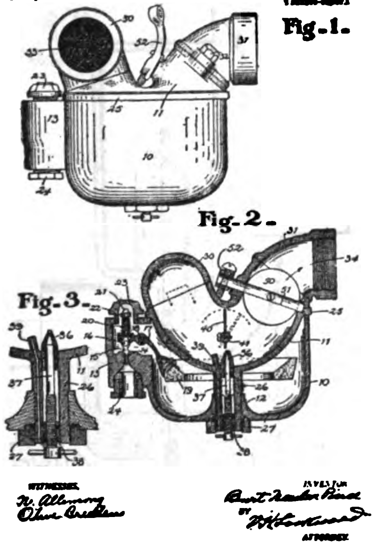

W. A. HATCHER.
CARBURETER.
Fig. 1.
Manually operated
To governor
Witnesses
Inventor
Attorneys


L. ANDERSON.
CARBURETER.
FIG. 1
FIG. 2
FIG. 3
FIG. 4
FIG. 5
Witnesses
Inventor
Lars Anderson
Attorneys

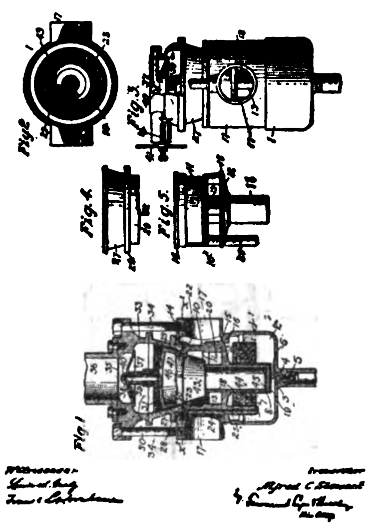

PATENTED JAN. 9, 1906.
CARBURETER FOR EXPLOSIVE ENGINES.
Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
Witnesses
Inventor

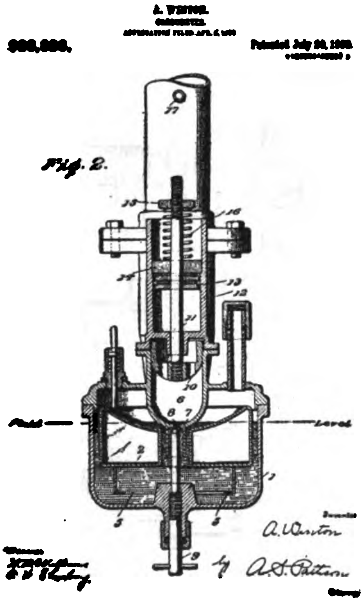

D. J. CARTWRIGHT.
CARBURETER FOR EXPLOSIVE ENGINES.
916,108.
Fig. 1.
Fig. 2.
Witnesses
Inventor
Attorney

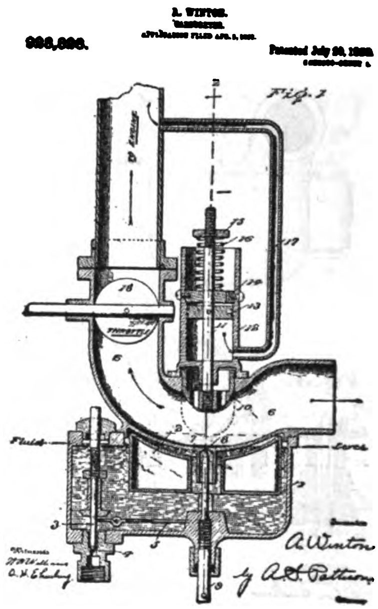
973,877.



994,900.

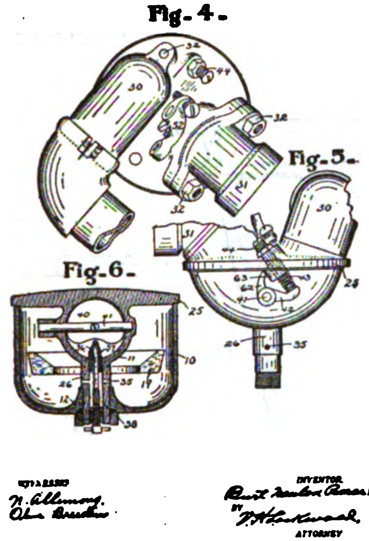



A. WINTON.
CARBURETER.
Fig. 2.
Level
A. Winton


A. WINTON.
Fig. 1
THROTTLE
Fluid
Level
A. Winton

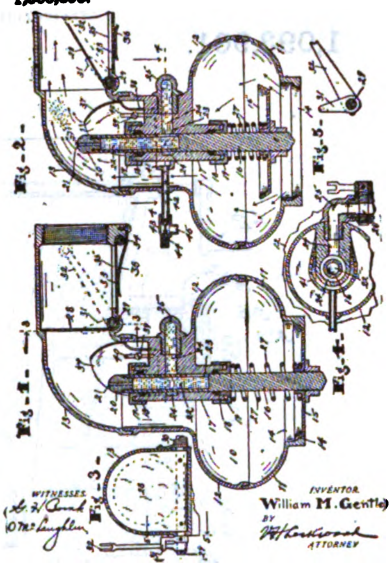
R. R. PIERCE.
CARBURETER.
APPLICATION FILED SEPT. 13, 1909.

973,877. Patented Oct. 25, 1910.
2 SHEETS—SHEET 2.



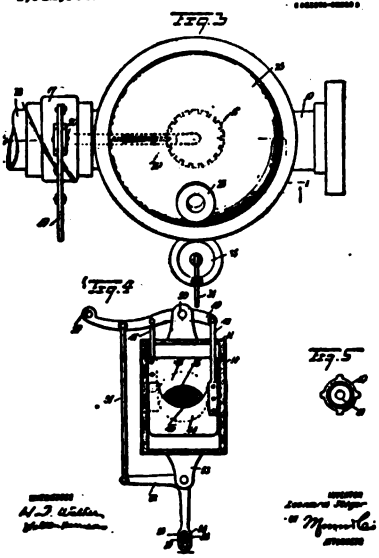
W. M. GENTLE.
CARBURETER.
APPLICATION FILED MAR. 8, 1910.

1,000,298. Patented Aug. 15, 1911.



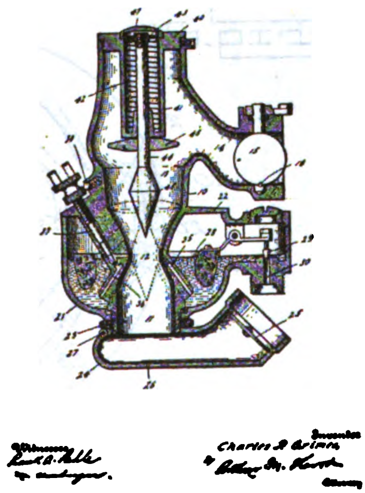
L. SLIGER.
CARBURETER.
APPLICATION FILED MAY 31, 1911.

1,042,982. Patented Oct. 29, 1912.
2 SHEETS—SHEET 2.



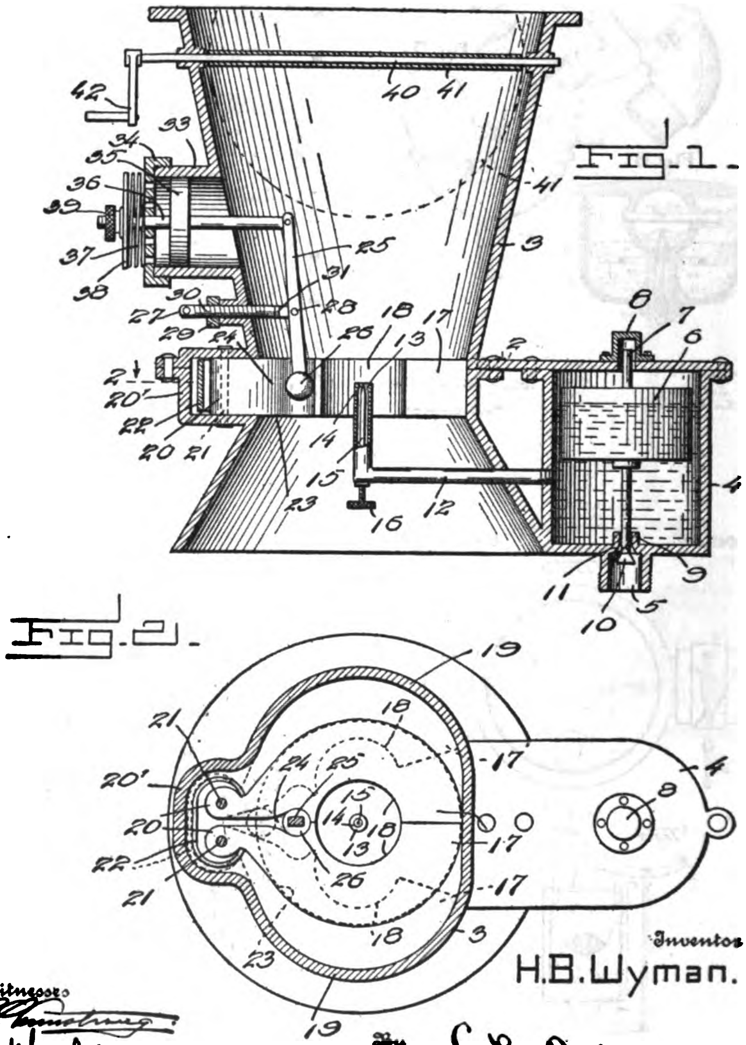
C. P. GRIMES.
CARBURETER.
APPLICATION FILED OCT. 31, 1910.

1,052,051. Patented Feb. 4, 1913.



H. B. WYMAN.
CARBURETER.
APPLICATION FILED DEC. 6, 1912.

1,093,901. Patented Apr. 21, 1914.



Witnesses

Inventor
H.B. Wyman.

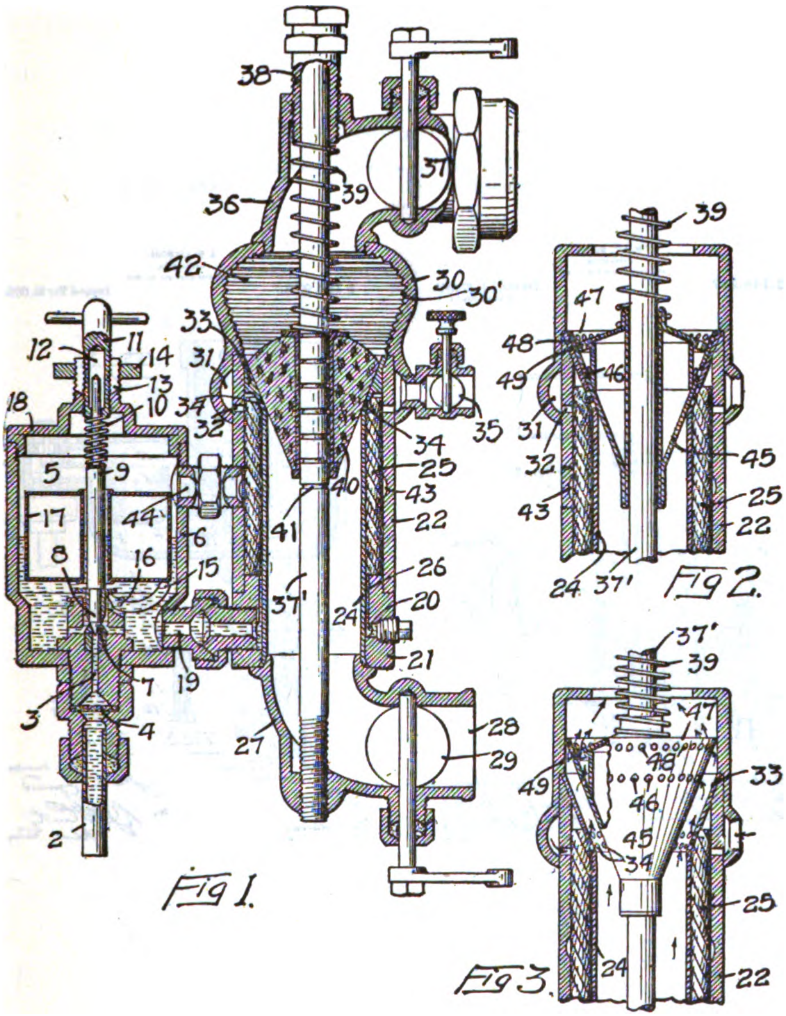
By C. L. Parker. Attorney

W. J. RUBESKY.

CARBURETER FOR EXPLOSIVE ENGINES.

APPLICATION FILED OCT. 11, 1909. RENEWED JUNE 17, 1914.

1,140,000. Patented May 18, 1915.

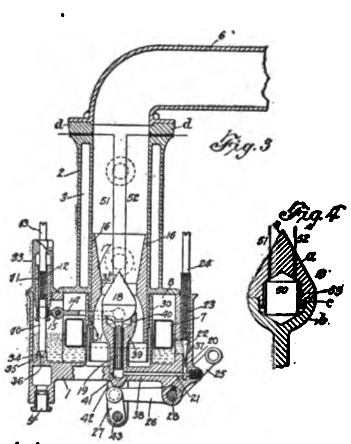


WITNESSES

INVENTOR
WILLIAM J. RUBESKY
BY Paul & Paul
ATTORNEYS

CARBURETER.

1,148,947. Patented July 27, 1915.

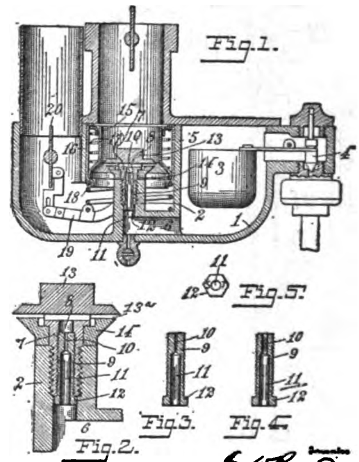


Witnesses

Inventor
William J. P. Moore

CARBURETER.

1,184,878. Patented May

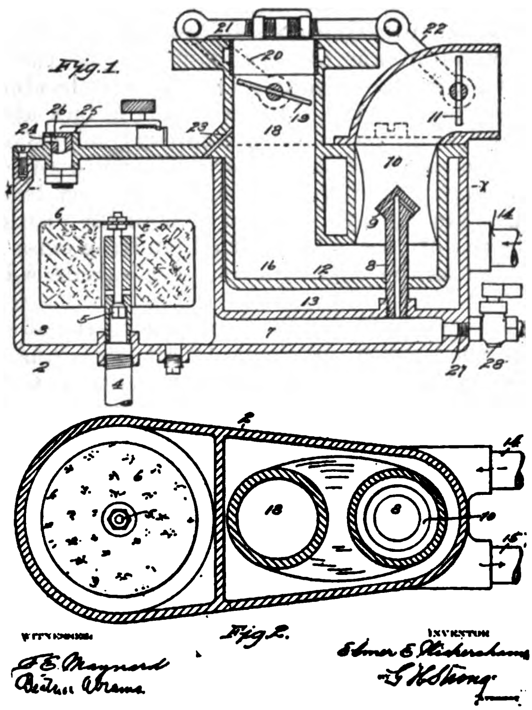


Witnesses

Inventor

E. E. WICKERSHAM.
CARBURETER.
APPLICATION FILED JAN. 26, 1914. RENEWED JUNE 1, 1915.

1,167,457. **Patented Jan. 11, 1916.**



another with a spring load, having also a linkage connection to an air damper on page 286 (1,184,873, May 30, 1916, Raymond).

Subclass 7.5, variable float-chamber pressure.—Use of a variable float-chamber pressure in connection with a regulating air inlet valve is practically equivalent to the use of two compensators at once. There are not many of such, and only one will be used for illustration, that on page 287. (1,167,457, Jan. 11, 1916, Wickersham.) This has an air valve, throttle controlled, which as pointed out, is not a primary connection for flow control with variable speed engines, as the fuel-flow vacuum is as much fixed by speed as by throat position, and in this case the float chamber pressure is reduced below atmosphere by a connection to the mixing chamber as a corrector of excessive fuel flow for high vacuum.

Class 8—Carburetors, proportioning flow, aspirating, single fixed fuel inlet, multiple air inlets valved for regulation.—It is the general opinion that the first systematic attack on a large scale of the problem of compensation in carburetors followed the lines of this class, compensation by admission of secondary air, so the class is one of peculiar interest on that account. For a considerable period this sort of compensation was the standard and in fact about the only thing in use; and being successful, comparatively speaking, much attention was devoted to devising more and more varied details of apparatus, resulting in a pretty large class. It may be said that the limitations of mechanical ingenuity, in view of the process characteristics, have only recently been recognized, and the class as a class no longer is regarded as the only or even an adequate solution of the problem.

Of course, there may be mixed flow or other means of compensation associated with these multiple variable air and single fixed fuel inlets, but these double compensations are exceptions to the standard arrangement of the class, which is that of a fixed primary air supply passing the fixed fuel jet, to which is added a variable secondary air.

While, according to the definition of the class there may be more than two air inlets, it will be found that in nearly all cases the multiplicity is equivalent in effect to two, one acting as primary and the other as secondary. The subclasses are characterized by the different combinations of commonly used means of control of the regulating air valve and by the number of such, with one exception, the last subclass, which includes any sort of control of the regulating air valve, provided it is associated with the mixed flow sort of compensation.

Those cases that do not clearly fall under the subclass headings, or that might with equal propriety fall under more than one of them, are grouped under the general class number and will be examined first. The general idea is that a properly regulated secondary air inlet will by dilution compensate for the natural tendency of a fixed fuel inlet in a fixed air passage to become over rich on increased flow. The problem is to evolve such a control of the secondary air that as the total flow rate increases the ratio of secondary to primary air shall also increase and in just the right amount.

An early case of special control of the variable part of the air is that on page 298 (751,434, Feb. 2, 1904, Napier & Rowlidge), one of the first of the automobile group of patents. The idea here is control

of secondary air with engine speed to compensate for the increased richness tendency, and a diaphragm operates on an air-sleeve valve. The diaphragm actuating pressure developed by a direct connected pump, which pressure should rise with speed. Of course, difficulty results where the engine speed varies without any change in fuel requirements, due to a variable resisting torque.

One of the early cases of multiplicity of air inlets of the mixed sort is that on pages 298 and 299 (828,228, Aug. 7, 1906, Menns & Menns), in which all the air first enters through an automatic air valve provided with a liquid dash pot, and then divides into three streams, two of them fixed in area crossing the fuel nozzle, and therefore acting as a single primary air, while the third varies with the throttle and acts as a sort of secondary, being not far enough beyond the nozzle to be a pure secondary. Another mixed case is that on page 299 (920,642, May 4, 1909, Pfander), where, although the secondary air is correctly located to act as such, it enters through two ports, one controlled directly by the throttle and the other automatic. This case also illustrates the idea of the warming jacket for the mixing chamber. Similarly mixed is the case on page 299 (929,260, July 27, 1909, Stevens), which provides besides, the fixed primary air, two automatic secondary air inlets, both annular and concentric with the nozzle. Two fixed air inlets, one directed directly across the jet and the other surrounding it, both acting as primary air but to different degrees, with a throttle controlled secondary air, is the combination illustrated on page 299 (970,916, Sept. 20, 1910, Gerken).

Location of the secondary automatic air valve beyond the throttle is shown on page 300 (1,001,969, Apr. 29, 1911, Maynard), where a fixed fuel and air inlet discharge their mixture through a check valve into the body of a cylindrical throttle beyond which the secondary air enters. Combination of compensation by throttle-controlled secondary air and by movable throat with reference to a fixed nozzle, is illustrated on page 300. (1,019,128, Mar. 5, 1912, Bulock.)

Double compensation of another sort is used in the construction shown on pages 300 and 301. (1,020,059, Mar. 12, 1912, Schulz.) An opening from the top of the float chamber to the mixing chamber is constantly in action and another opening from the float chamber to the atmosphere, is clased by the stem of the automatic secondary air valve when that is closed, and opens with it. Accordingly the starting or low-flow rate takes place with subatmospheric pressure in the float chamber and this lasts until the secondary air valve opens, at which time the float chamber pressure builds up, increasing the fuel flow as does the nozzle throat vacuum with air flow, and the secondary air as well.

A case of combined throttle and automatic control of the air is shown on page 301 (1,073,473, Sept. 16, 1913, Claudel), in which there are three air ports, one secondary and two primary, and of the latter one is fixed, while the other varies with the throttle, as does the secondary. The air for both of the throttle-controlled ports, one primary and one secondary, enters through an automatic valve. One odd case is that on page 301 (1,099,086, June 2, 1914, Hamilton), which illustrates not only an unusual air-inlet arrangement, but also the use of a burner for heat in combination with a proportioning flow carburetor. An oil-burner chamber with a pilot and a main jet,

is attached to the side of the carburetor and has itself two air inlets, one fixed and the other automatic. The main air for the engine fuel enters through an automatic valve and the mixture made by it passes through a nest of flame-heated tubes, together with the products of combustion of the burner, which carry excess air. The carburetor throttle controls the main burner jet, and compensation of proportions is expected from the tilting of the automobile carrying the device, uphill position increasing the fuel-flow head. It must be admitted that the interesting feature of this combination is rather its suggestiveness than its practical value.

Automatic valve control of primary air with a fixed secondary, the reverse of the usual arrangement, is shown on page 302 (1,104,762, July 28, 1914, Ahlberg), in which there is also illustrated the piston type of control of the automatic valve, spring loaded, and acted on by the vacuum at any selected point of the system, as well as the entraining idea of a jet and throat to induce a secondary air flow by that of the primary. A water nozzle is also shown beside that for fuel.

Another unusual sort of thing is that on page 302 (1,119,757, Dec. 1, 1914, Kings.) Here the primary air inlet is fixed and leads through a multiplicity of crossing passages, in the course of which the fuel is met and carried along, being thereby subjected to a spraying action before meeting the automatic secondary air. The action of the primary air and fuel passages is much the same as in the spray nozzles of some direct injection heavy oil engines. A similar use of one of the air inlets for spraying purposes, but in a different way, is shown on page 302 (1,127,992, Feb. 9, 1915, Hartshorn), where three air inlets are provided, a small fixed primary spraying stream entering a tubular jacket surrounding the nozzle, a main primary air inlet passing the nozzle, and a secondary air beyond the last two, both entering through automatic valves of different size and which may be different loaded. Still another case of a spraying air stream is that on page 303 (1,123,955, Jan. 5, 1915, Tice), applied to a carburetor of the sort in which the main air valve becomes the throttle and the float-chamber pressure is equalized with that at a selected point of the vacuum chamber for compensation. Here the spraying air inlet is fixed within the fuel nozzle and its size such as is proper to admit all the air needed for idling when acted on by the full vacuum due to a closed throttle, or in this case air-inlet valve. Here the main idea is spraying and vaporization instead of proportionality compensation, which, by reason of the limits of the critical air-velocity law, appears to be difficult, if not quite impossible. In accordance with this law the air flow fails to increase when the absolute pressure on the vacuum side of the inlet passage passes below 60 per cent in round numbers of the barometric as it does for lesser vacua, whereas the fuel flow does increase regularly.

Throttle control of a single main air inlet with similar throttle control of subsequent air distribution as secondary and primary air is illustrated on page 303. (1,137,307, Apr. 27, 1915, Edens.) This is a case of fixed primary air to a venturi, with secondary air controlled by throttle, and with the pressure at which both supplies are received also controlled by the throttle to something below atmosphere, the double air valves acting themselves as throttle.

A flat rectangular throttle arranged to always direct the entering air across a long slot form of fuel inlet or a row of holes equivalent thereto, with an automatic secondary air valve is shown on page 303. (1,151,989, Aug. 31, 1915, Balassa.) This is one of the cases where the primary proportionality is determined by the air-velocity head vacuum on the fuel flow, with automatic air-valve compensation, the primary air valve being itself the throttle, and the fuel inlets so located in front as to receive none of the air entrance resistance vacuum.

Subclass 8.1—two air inlets, fixed primary, throttle-controlled secondary regulating air valve.—Compensation through a throttle-controlled valve of any kind, as has already been pointed out, is of little, if any, value for variable speed engines where flow velocity is not of itself determined by throttle position, however much this may approach the truth in constant speed engines. The examples of this subclass must therefore be regarded as interesting in only an indirect way for general-service carburetors and not as promising or valuable schemes for any variable speed work, though they were used considerably in the early days of the automobile, before the real nature of the problem was as well understood as it is to-day.

One of these early automobile cases is that on page 304 (733,625, July 14, 1903, Clement), showing secondary air controlled by the rotation of a barrel form of throttle, for diluting and so compensating the mixture from a fixed fuel and primary air inlet. Similar control by the longitudinal movement of a barrel throttle is shown on page 304. (794,951, July 18, 1905, Schaaf & Lacy.) A combination of damper throttle and cylindrical balanced secondary air valve is shown on page 304 (851,285, Apr. 23, 1907, Freeman); a damper throttle with a sector slide air valve on page 304 (954,630, Apr. 12, 1910, Howarth); and a damper throttle geared to a rotating cylindrical secondary air valve on page 305. (1,011,565, Dec. 12, 1911, Brock.) This last case also illustrates an annular form of fuel inlet so that the fixed primary air inlet surrounds the variable secondary, which is central.

While, of course, control of secondary air with the throttle normally means that the port is actuated directly by or from the throttle, the same result follows precisely, if both are simultaneously operated from the engine mechanism as on page 305. (1,060,053, Apr. 29, 1913, Winkler.) Here the throttle is the engine inlet valve, operated by a cam, while another cam operates the secondary air valve at the same time, over a corresponding though perhaps shorter interval. The primary air is reduced to hardly more than what will serve for spraying purposes.

Use of a lifting tube in connection with a combined cylindrical throttle and secondary air inlet is shown on page 305 (1,097,401, May 19, 1914, Donndorf), where the spillage from the jet at low-flow velocities is caught in a shroud tube surrounding the nozzle, the bottom of which is led beyond the throttle to maintain a steady feed when idling, as is done so frequently in other classes of carburetors. A case of primary air direction by guides combined with throttle control of secondary air is shown on page 306 (1,123,027, Dec. 29, 1914, Simonson), which is also peculiar in having two sets of holes in the top of the float chamber, one to the primary passage beyond the jet, and the other to a low point of the secondary mixing

chamber, provided to drain back unvaporized fuel. It is a question just how these holes will act, but it is clear that they will result in some modifications of float chamber pressure and therefore of fuel control.

Two dampers linked together, one as throttle and the other as secondary air valve, are shown on pages 306 and 307 (1,148,898, Aug. 3, 1915, Henley), which case also has two other peculiarities. In the first place the primary air is so small in amount as to be practically no more than spraying air, exerting little control on the amount of fuel flow, but some, and, second, the entrance of the secondary air is guided by curved vanes to produce a vortex at the jet to secure a main control of fuel-flow vacuum. One of the most recent cases and of peculiar form is that on page 307 (1,185,273, May 30, 1916, Atherton), which has a secondary air valve linked to the throttle, both of damper form but with an automatic valve to control the amount and the velocity of the secondary air that shall pass the outlet of the primary air and its fuel or completely by-pass it.

Subclass 8.2—Two air inlets, fixed primary, automatic secondary regulating air valve.—As a subclass this is a very large, if not the largest one of all, which is not unnatural, considering the scope it offers to the mechanically ingenious. The principle is entirely sound and correct qualitatively; and this coupled with the fact that compensation by adding an automatic secondary valve, the simplest form of which is the spring-loaded check, seems a simple, cheap, and easy thing, is responsible for the flood of inventions along this line. The difficulty is one of degree, because the compensation means must be not only right in principle but must be so also in amount, and the real problem is one of design of secondary air valves in form, size, and especially in loading so they will give just the right compensation and keep it so, without variation throughout the life of the carburetor. No better example of the inadequacy of invention alone without the quantitative relationships of design, distinguishing it from invention, could be found, than this class so voluminous as to invention and so unsatisfactory as to practical commercial results in proportion to the effort expended.

One of the early cases of this subclass, that on page 308 (649,324, May 8, 1900, Longuemare) associates an automatic secondary air valve of annular form, concentric with the primary, with a fuel inlet of several slots cut in the face of a tapered plug on a matching seat, the fuel inlet being located in a short straight primary air tube generally termed a choke or strangle tube. A somewhat similar form of fuel inlet arranged in the wall of the primary air passage and associated with a cross-flow automatic secondary is shown on page 209. (759,001, May 3, 1904, Mohler.) One of the most important of the cases of this class, page 308 (785,558, Mar. 21, 1905, Krebs), uses a balanced secondary air valve operated by a spring and diaphragm, controlled by the vacuum in the secondary air passage. This case is interesting because the inventor was the first and most vigorous advocate of this type of compensation and by his publications on the subject was responsible more than any other individual for the stimulation of world-wide interest in the class. An automatic secondary air valve loaded by the buoyancy of a float in mercury is shown on pages 308 and 309 (802,216, Oct. 17, 1905, Johnston), which at once calls attention to the problem of valve loading.

It is evident that if proper compensation is to be attained with the normal arrangement of fixed fuel inlet in a primary air-choke tube, the secondary air must increase in proportion to the total, and this requires a variable loading with opening, which can not be obtained by gravity alone might be, but is difficult with springs alone, could by combination of links and cams with gravity and spring forces, or by their equivalent, buoyancy against float shape. The rest is matter of practicability.

An annular spring-loaded automatic secondary air valve is shown on page 309 (810,792, Jan. 23, 1906, McIntosh), which has a peculiar element. The choke tube is of the tapered form and is part of the air valve, so the fuel inlet finds itself at a wider part of the choke tube when the secondary lifts than before. This makes the compensation double, first, by secondary air in the ordinary way, and, second, by the variable throat and nozzle relation itself. A flat-ring form of air valve is shown on page 309 (831,832, Sept. 25, 1906, Coffin), which on lifting supplies a double air stream, one directed toward the center and the other outward, and only the latter is truly secondary, because the former by its velocity across the fuel inlet acts substantially as does the primary air in inducing fuel flow.

As an example of loading by means of a combination of links and springs to secure a particular rate of opening with vacuum, the form on page 310 (835,880, Nov. 13, 1906, Clement) is of interest.

An attempt at direct relationship of secondary air to total mixture is found on page 310 (856,958, June 11, 1907, Huber), where the secondary air valve is balanced and not affected by the vacuum at all, but is moved by a floating spring-resisted check valve in the main stream of mixture, the lift of which is more or less directly related to the total flow.

All of the previous cases in which the secondary air valve is opened by the vacuum use the vacuum at a point beyond the primary mixture inlet, usually at an enlarged chamber where the velocity is low, but in the following case there is a departure from this practice. On pages 310 and 311 (860,848, July 23, 1907, Bowers) the primary mixture discharges from a restricted orifice in the center of the throat of a larger venturi tube, and through the annular space thus formed the secondary air enters after passing its automatic valve. The vacuum at this high-velocity point controls the opening of the automatic valves instead of that at some more distant chamber or low-velocity point.

An indirectly loaded secondary air valve is shown on page 311 (888,487, May 26, 1908, Greuter), where a simple lever and spring are used instead of a direct spring, but with no different force or loading characteristics. Arrangement of the secondary air valve at the highest point with a long vertical primary mixture lifting tube is shown on page 311 (888,965, May 28, 1906, Delanay-Belleville), which is of interest not because of any peculiar compensating value, but because of its adaptability to low-volatile fuels now so common and which are difficult to handle at low-flow rates because the velocity is not high enough to lift the unvaporized liquid when, as is usually the case, the float chamber must be set low. Recognition of one of the practical difficulties of the automatic air valve is found on page 312 (912,083, Feb. 9, 1909, Daley), where there is provided a liquid dash pot to dampen the movement of the automatic air valve. The

fuel is itself the dash-pot liquid, and the valved form is used, permitting free downward movement corresponding to flow increase but restricted upward movement. An unusual form of fuel inlet is also shown, an annular slot formed between a rod and a concentric hole in a plate. The form of the air valve with its long tapers is also a recognition of the need of a graduated opening with vacuum. A special form of spring loading for the automatic air valve is shown on page 312 (927,529, July 13, 1909, Harrington), where a flat flexing spring with an adjustment for its free length is provided. Location of the automatic air valve in a side chamber, a pretty common arrangement in the later forms, and the use of the tapered primary air-choke tube, also more and more frequently adopted later, are illustrated on pages 312 and 313 (928,042, July 13, 1908, Goldberg).

An interesting form of graduated air valve is that shown in figure 222 (932,860, Aug. 31, 1909, Groubille & Arquembourg), where a number of metal balls of varying size constitute the air valve, or, rather, a set of air valves of different size and opening resistance, and these are shown as associated with the venturi form of primary inlet. Another example of ball-type air valve is shown on page 313 (974,076, Oct. 25, 1910, Kingston), where the balls are all the same size, but their seats are of different diameters.

A special valve-loading mechanism is illustrated on page 314 (976,558, Nov. 22, 1910, Dayton), a sort of clock spring and gear train, and another still different on page 314 (976,692, Nov. 22, 1910, Riechenbach), this latter associated with a swing form of valve and introducing cams to secure the force variation required with reference to vacuum and valve opening. Flexing flat spring strips over slots to make an automatic air valve are shown on page 315 (997,233, July 4, 1911, Bowers). Control of the automatic air valve by the vacuum at the throat of the primary venturi instead of that beyond it, on the theory that this throat vacuum is itself a measure of air flow and can properly be made a prime factor in the motion of the air valve, is illustrated on page 315 (1,067,502, reissued as 13,784, Aug. 4, 1914, Brown).

The long curved shape of the valve face itself acts in a manner equivalent to a cam type of valve loading and a somewhat similar idea of valve face form used with direct spring loads against the main mixing-chamber vacuum is shown on pages 315 and 316 (1,069,671, Aug. 12, 1913, Brush), associated with a direct-acting lifting tube by-passing the throttle. A differential form of air valve is shown on page 316 (1,071,858, Sept. 2, 1913, Ball & Ball); also direct spring loaded and opened by main mixing-chamber vacuum, but having a quite small fixed primary air inlet, in which is a special form of fuel inlet, a capillary annulus formed between a long tapered wall and a corresponding rod.

An example of two automatic secondary air inlets which in action are equivalent to one is given on page 316. (1,086,287, Feb. 3, 1914, Gehrmann.) An automatic air valve form adapted to be influenced to the maximum degree by the velocity of the passing air is shown on page 316. (1,092,282, Apr. 7, 1914, Mixsell.) Here the reversal of flow direction produces a reaction assisting the opening and equivalent to an increase of vacuum or a decrease of spring tension. Double-spring loading of the automatic air valve is shown on page 317 (1,112,257, Sept. 29, 1914, Brush), where the second spring comes

into action to increase the loading after the valve movement has exceeded a given value. It also illustrates again the high-point location of the air valve with a long lifting primary tube for low float chambers. The primary and secondary streams approach the throttle from opposite directions, and the throttle itself distributes the mixture to four cylinders by four ports, each feeding a separate mixture passage. Heating of the secondary air between the valve and the mixing point is illustrated on page 317 (1,140,064, May 18, 1915, Rakestraw), which also shows a heated and baffled mixing chamber. Such heating, if not quite constant, causes a variable expansion of the air, affecting flow as would a varying resistance of passage, and this interferes with proportionality.

A sort of floating automatic secondary air valve is shown on pages 317 and 318 (1,143,961, June 22, 1915, Haynes), formed somewhat like a perforated nozzle cap, the primary air being fixed by the holes in the cap and the secondary varying with its lift. There is also shown a wick air humidifier in the primary air. Electrical heating of both the air and the fuel separately in connection with an automatic air valve of the clock form is illustrated on page 318 (1,150,619, Aug. 17, 1915, Percival & Patterson), one of a large number of cases where the attention being concentrated on the problem of applying heat to vaporize heavy fuels has led to the introduction of proportionality interferences by variable back-pressure effects in the case of the air and variable viscosity and efflux effects on that of the fuel.

With the idea of promoting acceleration on a sudden opening of the throttle, a special form of throttle carrying the automatic secondary air valve has been arranged, as shown on page 318. (1,162,576, Nov. 30, 1915, Daimler & Slaby.) A quick opening of the throttle by a sort of dashpot action momentarily closes the secondary air valve and enriches the charge accordingly, but immediately afterwards the position due to the vacuum is taken up automatically. This is equivalent to the accelerating cup, except that it acts equally at any position.

Subclass 8.3—Two air inlets, both with regulating valves, one automatic, the other throttle controlled.—One case will serve to illustrate this unimportant mixed class, that on page 319 (1,060,545, Apr. 29, 1913, Gentle), which has the main primary air entering through an automatic valve and the secondary controlled by the throttle. A peculiar form of fuel inlet is provided, characterized by capillary flow, which consists of a wire screen in a narrow annular slot, the screen being cylindrical and carried by the automatic valve.

Subclass 8.4—Two air inlets, both with automatic regulating valves.—As compared with fixed primary air, the case of primary air entering through an automatic valve with a fuel inlet beyond it would require rather less compensation for proportionality because of the increasing area of air entrance which directly tends to retard excessive rise of vacuum, especially with gravity loaded valves as compared with spring loaded. In fact, with a gravity loaded primary air valve and a fixed fuel inlet beyond it insufficient fuel will enter at high flow rates unless some special arrangement is introduced to force it, because the increase of vacuum and hence fuel flow, with reference to air flow, is negligible. With spring loaded valves having an increasing tension there may be required more or less compensation which might be obtained with a secondary spring load. In gen-

eral, there is likely to be rather too much trouble and difficulty in getting a proper spring loading for one valve to warrant trying it with two, so this subclass is one of doubtful practical value, though within the range of qualitative possibility. Location of the fuel inlet at or before one of the automatic air valves is one more or less common special arrangement where the case is least complex.

In the form page 319 (762,707, June 14, 1904, Grove) the fuel inlet is in the seat of the primary automatic valve. If, as is most often the case, it may be assumed that this valve when it opens at all opens full against its stop, then this is equivalent to a fixed fuel and a fixed air inlet arranged for gravity flow of fuel for slow-speed engines. The secondary air being automatic, the case is one that might be assigned to the subclass 8.2, as adapted for periodic opening of a fuel valve with pressure feed.

With the arrangement on page 320 (790,173, May 16, 1905, Biehn) the situation is quite different, for here a double valve with a single spring load operates so as to decrease the primary air as the secondary air increases, the former being controlled at the outlet point of the primary air and its fuel. Location of the fuel inlet in the path of the primary air entering through an automatic valve, gravity loaded so as to receive the direct velocity head vacuum action which should be nearly constant, is illustrated on pages 320 and 321. (806,830, Dec. 12, 1905, Packard.) The secondary air opens after the primary opening has exceeded a given value, and a single valve controls both openings. A pair of conically helical spring forms of valve is shown on page 321 (960,080, May 31, 1910, Fay & Ellsworth), with the fuel inlet located in a fixed air passage in front of one of these spring automatics, which controls the primary air at its outlet. This arrangement so far is equivalent to a fixed air and fuel with an outlet throttle and tends to become rich, so a secondary air valve is a corrective. In this case the tension of both spring valves is subject to hand control so they may be made to serve as throttle.

A somewhat odd case, having a fuel inlet in the seat of one automatic (as in 762,707, Grove), is that on page 321 (1,136,675, Apr. 20, 1915, Hutchinson), where special means are provided between the two valves for separating out and drawing away the unvaporized fuel. This shows the later recognition of the prevalence of nonvolatile fuel and the necessity for some means of dealing with the unvaporized liquid portions, but a rather questionable way, because any fuel thus drained away is responsible for just so much interference with proportionality otherwise established by the flow. This returned liquid being the heavier portion, it can not be used again in the same sort of carburetor with any more hope of vaporizing the second time than the first, in fact, less.

One example of an arrangement that requires rather less than more compensating action of the secondary air valve is shown on page 321 (1,183,137, May 16, 1916, Swarts). Here the taper throat of the primary air passage lifts automatically, thereby tending to compensate directly, and the secondary automatic air valve is expected to do the rest. The effect of this arrangement should be similar to those of subclass 8.2.

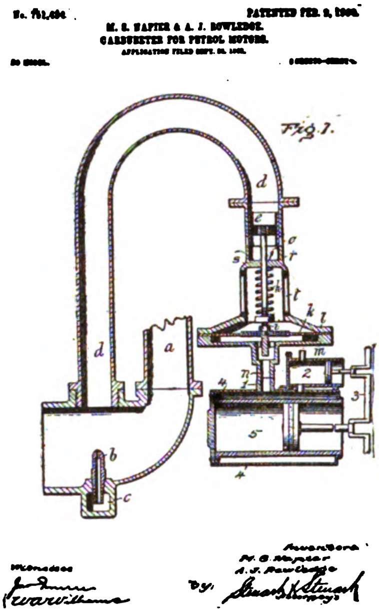
Subclass 8.5—Two air inlets, both with throttle controlled regulating valves.—With the reminder that such direct throttle control is only, or mainly, of interest in connection with constant-speed engines,

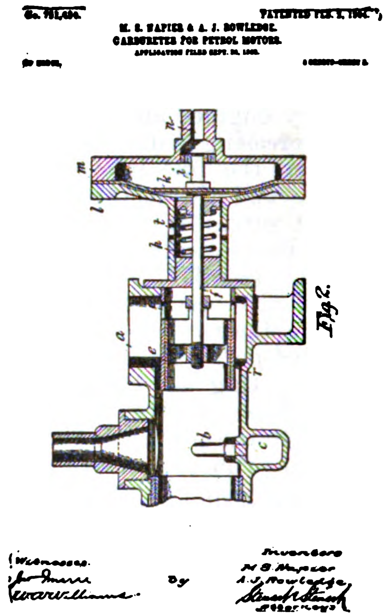
this class assumes but small importance in the general carburetor case, which includes the variable-speed engine.

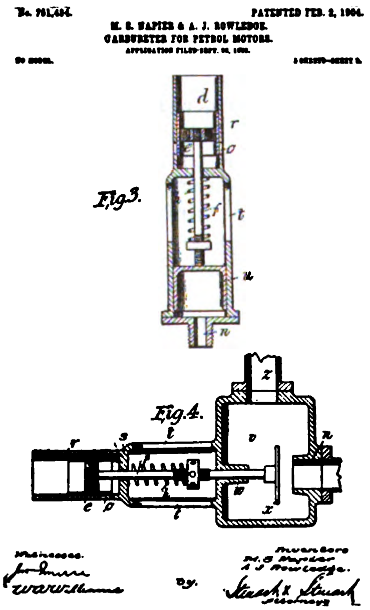
Two air valves acting as throttle and so formed as to be really a double-ported single valve is the arrangement on page 322 (714,597, Nov. 25, 1902, Mors), originally intended for automobiles. The next case (856,638, June 11, 1907, Higgins), is one of those designed for stationary engines and has two air inlets, one increasing and the other decreasing with the throttle, so arranged as to control the vacuum at the fuel inlet. A double-ported slide valve, acting as air valve and throttle, has a fuel nozzle in front of one in the port that serves as a primary air passage, while the second port controls the secondary air simultaneously in the construction on page 322. (846,471, Mar. 12, 1907, Hobart.) The same case illustrates a double-beat disk valve and a damper valve acting in the same way. A cylindrical sleeve, constituting the tapered air throat by its two sets of ports, acting as throttle and auxiliary air valve, and its free and acting as primary-air valve, is illustrated on page 322. (905,012, Nov. 24, 1908, Spranger.) The motion of the throat, with reference to the jet nozzle is itself a compensating influence, leaving less for the primary and secondary air ports to do.

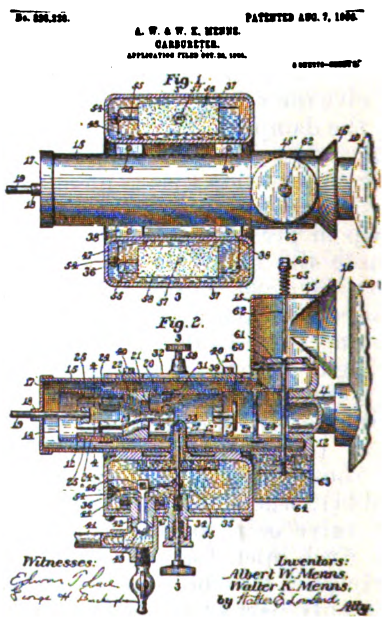
A sliding semicylindrical plug throttle moving across a pair of air ports, one of which carries the fuel inlet, and thereby controlling the total air and the ratio of primary to secondary air is shown on page 323. (988,800, Apr. 4, 1911, McHardy & Potter.) Two damper valves arranged to act at the same time as air valves and throttle may be made to accomplish at least qualitatively the desired compensation for constant speed engines when arranged as on pages 323 and 324 (1,014,328, Jan. 9, 1912, Podlesak.) A double air passage has a damper in both branches, so linked together as to give the compensation desired, the fuel nozzle being located in one of them as as to receive the velocity head vacuum of one of the four air streams formed by the dampers.

Subclass 8.6—mixed flow.—One very early case of the direct sort of compensation that is possible by the mixed flow principle, but used in conjunction with a variable main air inlet to minimize the total drop in pressure through the carburetor as compared with the class where the main air inlet is fixed is that on page 325. (423,214, Mar. 11, 1890, Butler.) Here the main air enters through a spring loaded automatic valve while the fuel enters in an annular stream around the outside of the seat of the main valve where the velocity is high. Compensation is secured by air flow to the fuel passage at a point just behind its outlet. Another case involving the same principle of compensation, but differently arranged, is that on page 325. (802,038, Oct. 17, 1905, Hagar.) A more recent case, and one of some interest, is that on page 325 (1,061,835, May 13, 1913, Gobbi), where the fuel inlet is set before the one valve that acts as air valve or throttle. This valve has a hole in it registering with the fuel inlet for idling on closed throttle, air for which enters through a side hole in the throttle itself. On opening the throttle suddenly part of the large air flow is caught by a hood and directed down a shroud tube around the nozzle, emptying it of fuel that collected during slow feed. This accelerating cup action is followed by a mixture proportionality compensating action when this same air enters the fuel nozzle through which the accelerating cup was filled.


M. S. NAPIER & A. J. ROWLEDGE.
CARBURETER FOR PETROL MOTORS.
Fig. 1.
Witnesses
Inventors
M. S. Napier
A. J. Rowledge
By
Attorneys

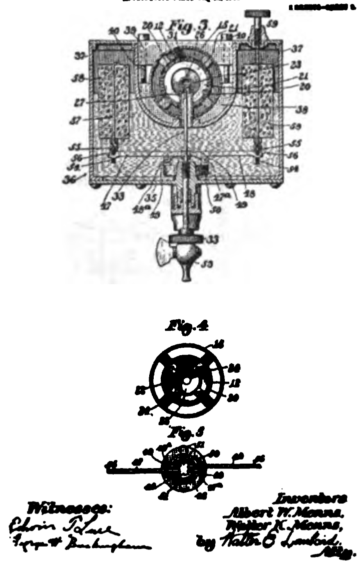

M. S. NAPIER & A. J. ROWLEDGE.
CARBURETER FOR PETROL MOTORS.
Fig. 2.
Witnesses.
Inventors
M. S. Napier
A. J. Rowledge.
By
Attorneys


PATENTED FEB. 2, 1904.
M. S. NAPIER & A. J. ROWLEDGE.
CARBURETER FOR PETROL MOTORS.
Fig. 3.
Fig. 4.
Witnesses.
Inventors
M. S. Napier
A. J. Rowledge.
By
Attorneys


PATENTED AUG. 7,
A. W. & W. K. MENNS.
CARBURETER.
Fig. 1.
Fig. 2.
Witnesses:
Inventors:
Albert W. Menns,
Walter K. Menns,
by
Atty.

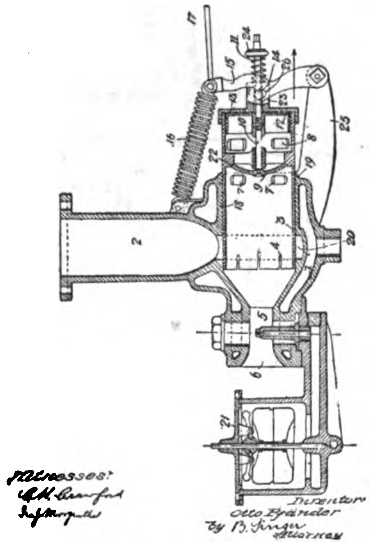
A. W. & W. E. MENNS.
CARBURETER.
APPLICATION FILED OCT. 26, 1905.

PATENTED AUG. 7, 1906.



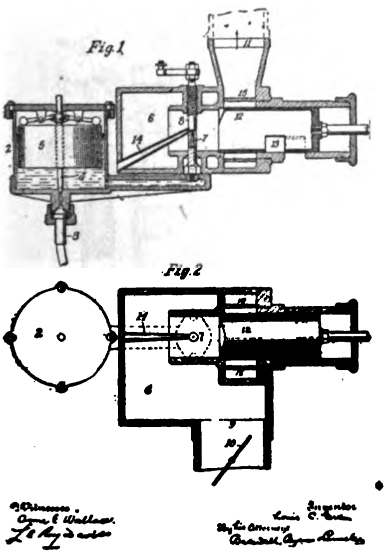
O. PFÄNDER.
AUTOMATICALLY GOVERNED CARBURETER.
APPLICATION FILED MAR. 1907.

920,642. Patented May 4, 1909.



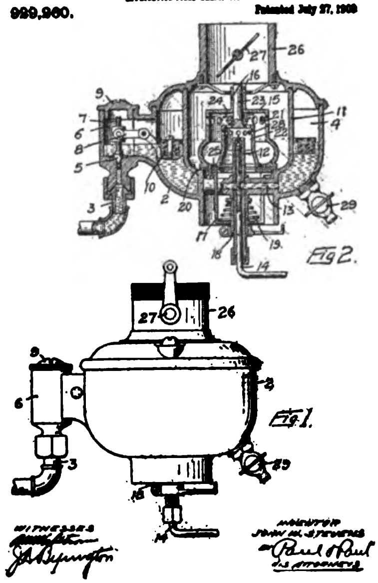
L. C. GERKEN.
CARBURETER FOR GAS ENGINES.
APPLICATION FILED APR. 1909.

970,916. Patented Sept. 20, 1910.



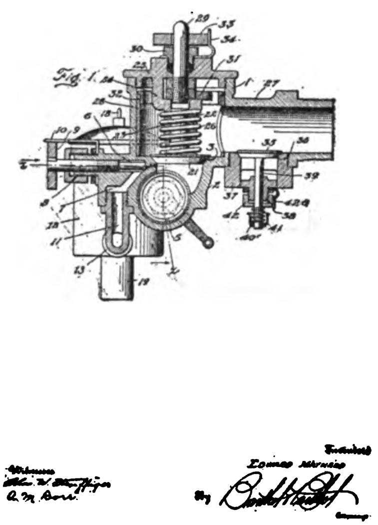
J. W. STEVENS.
CARBURETER.
APPLICATION FILED MAR. 1909.

929,960. Patented July 27, 1909.



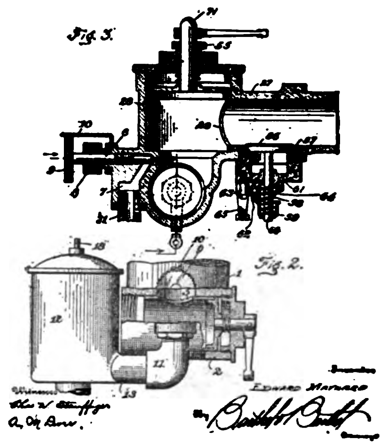
E. MAYNARD.
CARBURETER.
APPLICATION FILED SEPT. 17, 1910.

1,001,969. Patented Aug. 29, 1911.



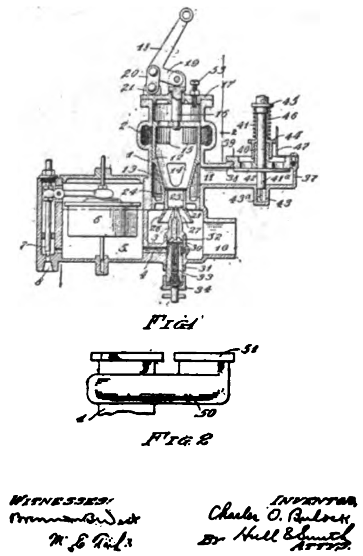
E. MAYNARD.
CARBURETER.
APPLICATION FILED SEPT. 17, 1910.

1,001,969. Patented Aug. 29, 1911.



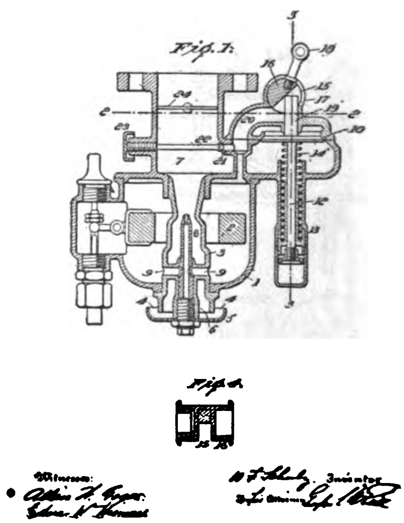
C. O. BULOCK.
CARBURETER.
APPLICATION FILED APR. 6, 1908.

1,019,198. Patented Mar. 5, 1912.



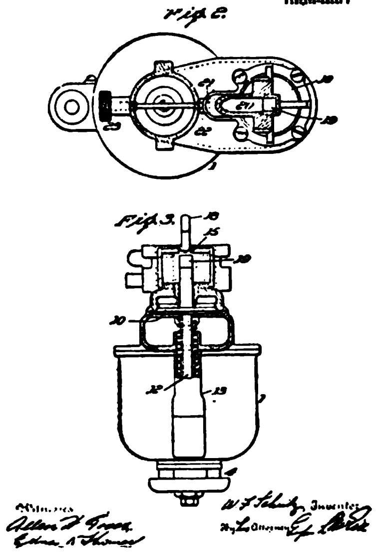
W. F. SCHULZ.
CARBURETER.
APPLICATION FILED NOV. 11, 1909.

1,020,059. Patented Mar. 12, 1912.



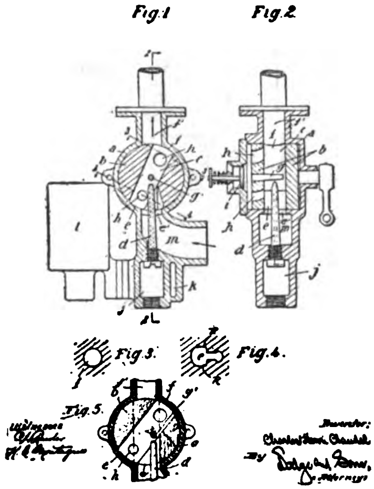
W. F. SCHULZ.
CARBURETER.
APPLICATION FILED [illegible]

1,020,059. Patented Mar. 12, 1912.



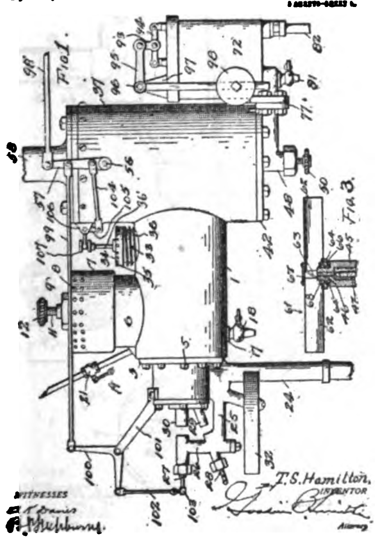
C. H. CLAUDEL.
CARBURETER.
APPLICATION FILED [illegible]

1,073,473. Patented Sept. 16, 1913.



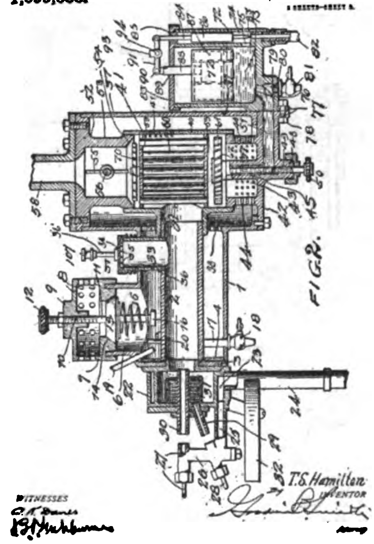
T. S. HAMILTON.
CARBURETER.
APPLICATION FILED [illegible]

1,099,086. Patented June 2, 1914.



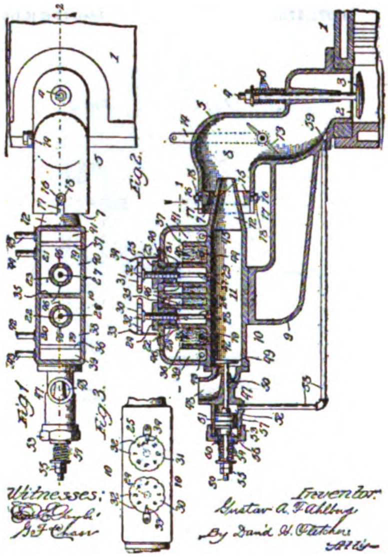
T. S. HAMILTON.
CARBURETER.
APPLICATION FILED [illegible]

1,099,086. Patented June 2, 1914.



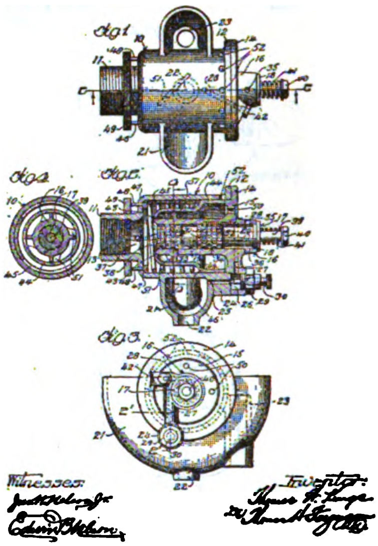
G. A. F. AHLBERG.
CARBURETER.

1,104,762. Patented July 28, 1914.



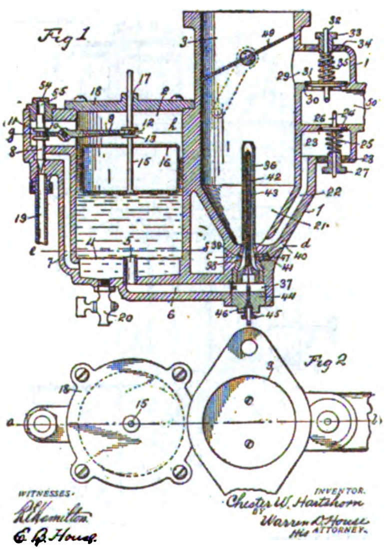
CARBURETER.

1,119,757. Patented Dec. 1, 1914.



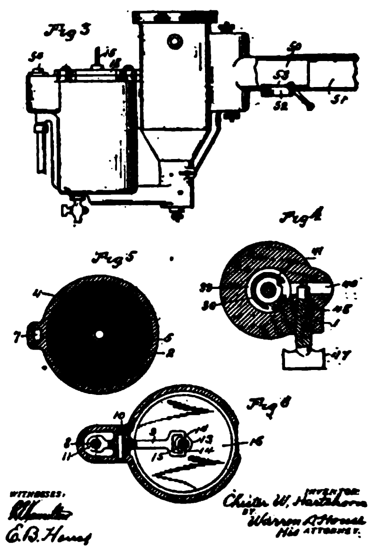
C. W. HARTSHORN.
CARBURETER.

1,127,992. Patented Feb. 9, 1915.



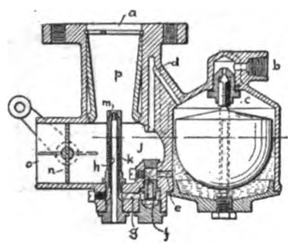
C. W. HARTSHORN.
CARBURETER.

1,127,992. Patented Feb. 9, 1915.



P. S. TICE.
CARBURETER.
APPLICATION FILED JAN. 6, 1914.

1,128,955. Patented Jan. 5, 1915.

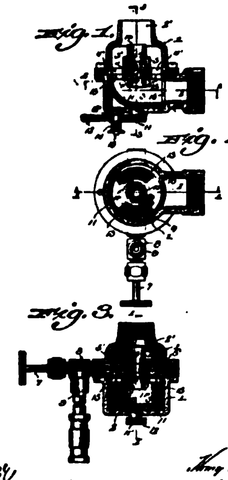


WITNESSES

INVENTOR
Percival S. Tice
BY
ATTORNEY

H. R. EDENS.
CARBURETER.
APPLICATION FILED JUNE 4, 1914.

1,137,307. Patented Apr. 27, 1915.

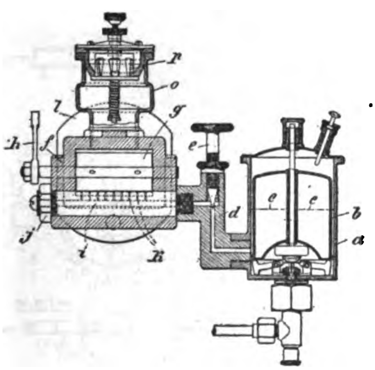


Inventor:
Harry R. Edens
Witnesses:
May Downey
By
Attorneys

F. BALASSA.
CARBURETER.
APPLICATION FILED FEB. 21, 1914.

1,151,989. Patented Aug. 31, 1915.
2 SHEETS—SHEET 1.

Fig. 1.

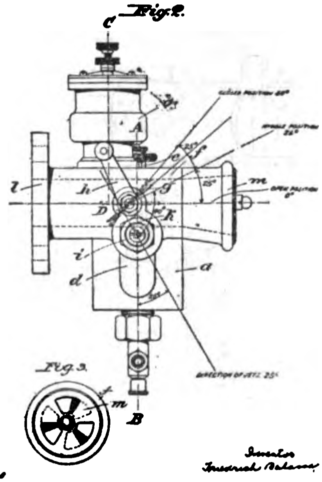


Witnesses
Inventor
Friedrich Balassa
Attorneys

F. BALASSA.
CARBURETER.
APPLICATION FILED FEB. 21, 1914.

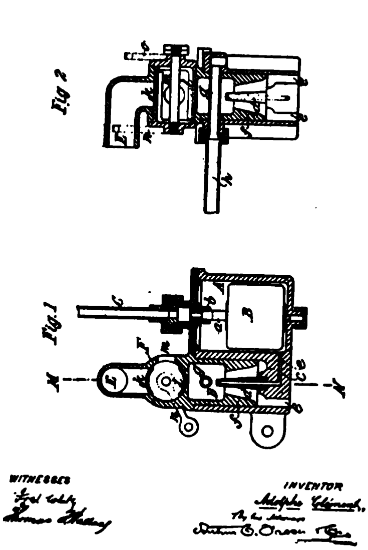
1,151,989. Patented Aug. 31, 1915.
2 SHEETS—SHEET 2.

Fig. 2.

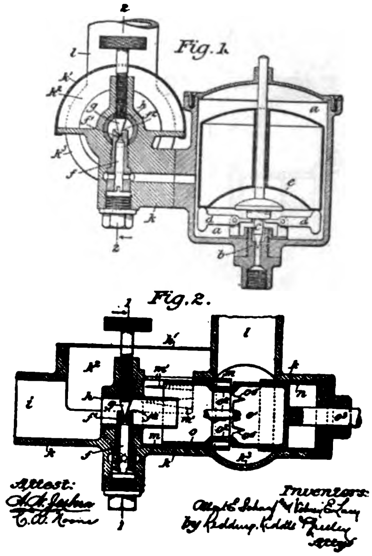


Witnesses
Inventor
Friedrich Balassa
Attorney

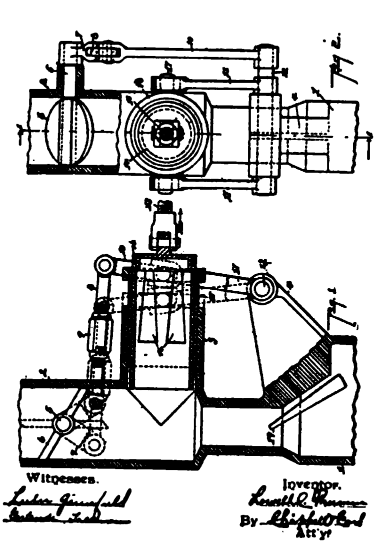
No. 733,008. PATENTED JULY 14, 1903.
A. CLEMENT.
CARBURETER FOR MOTOR BICYCLES.
APPLICATION FILED JUNE 4, 1903.
NO MODEL.



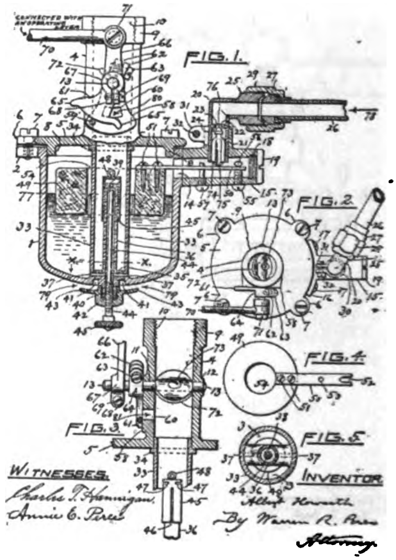
No. 764,951 PATENTED JULY 12, 1904.
A. E. SCHAAF & V. E. LACY.
CARBURETER.
APPLICATION FILED MAY 2, 1903.



No. 851,906 PATENTED APR. 30, 1907.
L. C. FREEMAN.
CARBURETER FOR AN EXPLOSIVE ENGINE.
APPLICATION FILED DEC. 10, 1906.

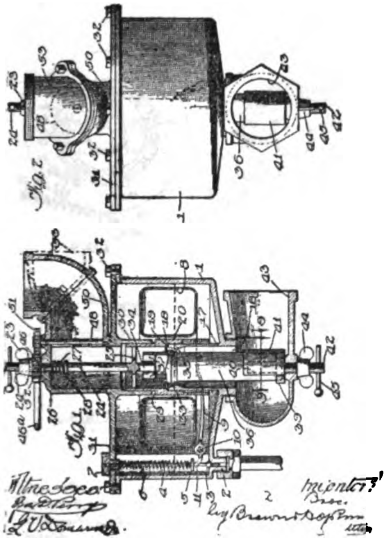


A. HOWARTH.
CARBURETER.
APPLICATION FILED JAN. 6, 1909.
954,630. Patented Apr. 12, 1910.



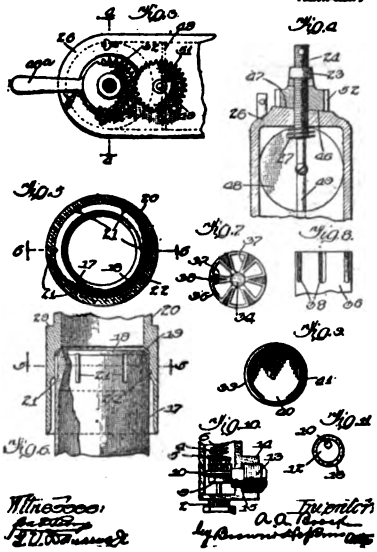
A. A. BROCK.
CARBURETER.

1,011,565. Patented Dec. 12, 1911.



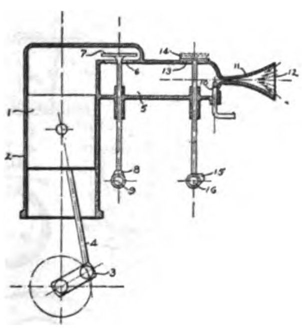
A. A. BROCK.
CARBURETER.

1,011,565. Patented Dec. 12, 1911.



O. WINKLER
CARBURETER.

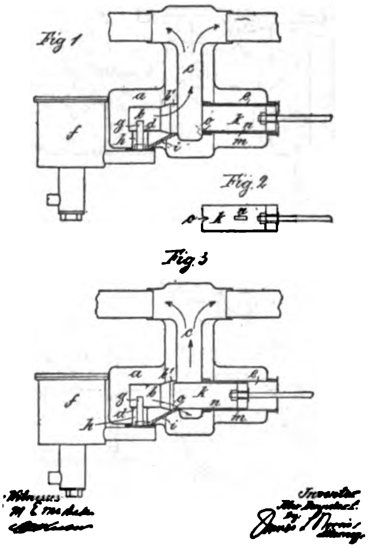
1,060,053. Patented Apr. 29, 1913.

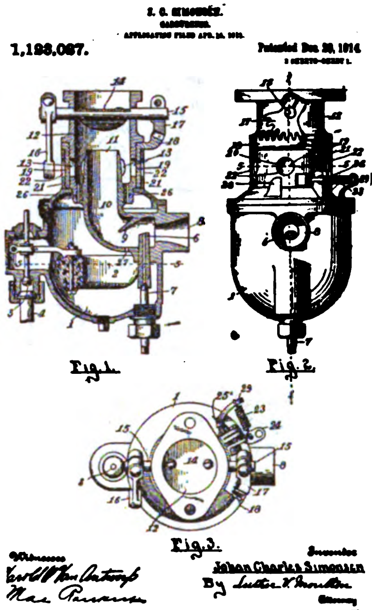


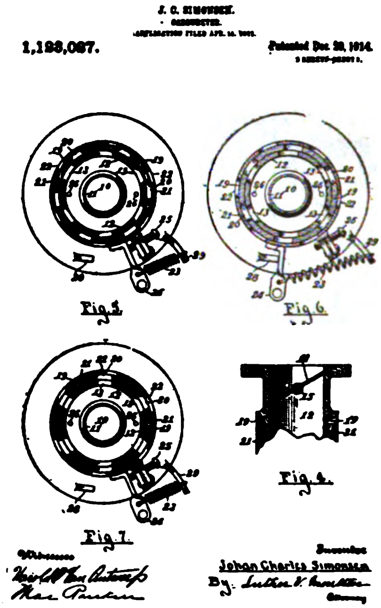
Witnesses | Inventor: Otto Winkler, By Atty.

P. DONNDORF.
JET CARBURETER.

1,097,401. Patented May 19, 1914.




1,123,087.
Fig. 1.
Fig. 2.
Fig. 3.
Johan Charles Simonsen
By


1,123,087.
Fig. 5.
Fig. 6.
Fig. 7.
Fig. 4.
Johan Charles Simonsen
By

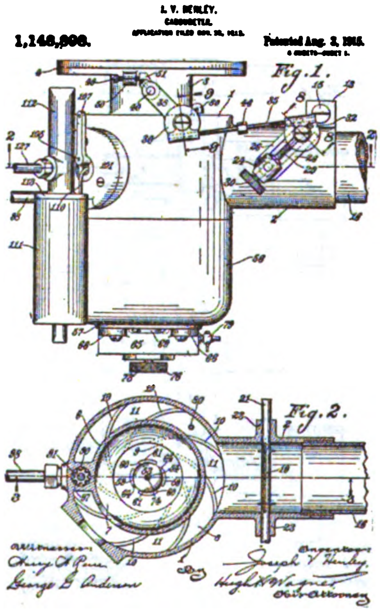


Fig. 1.
Fig. 2.

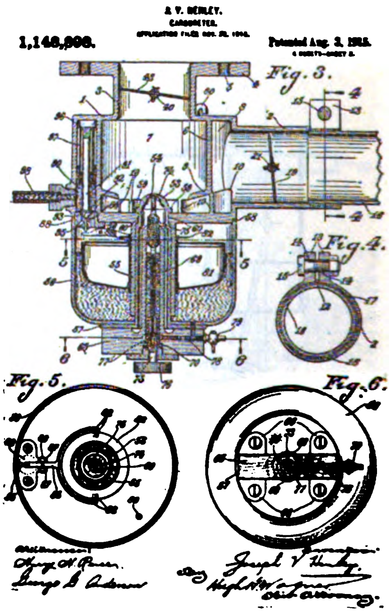
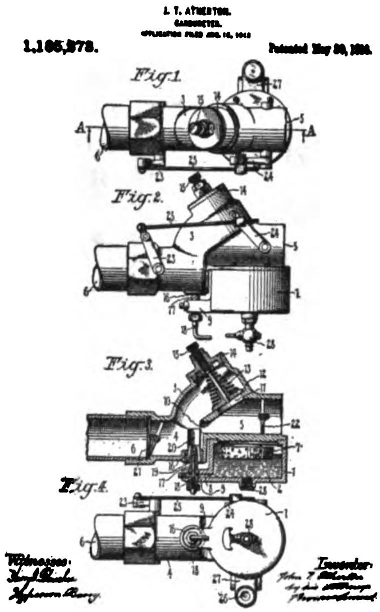
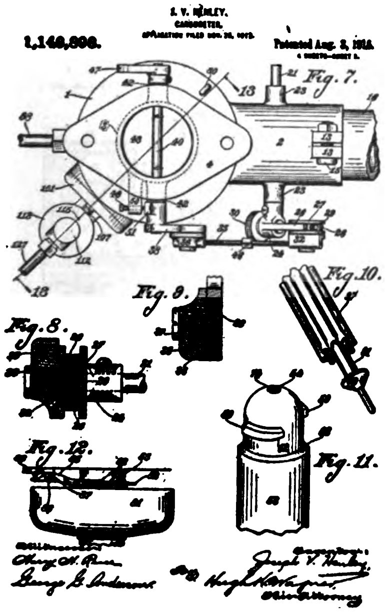
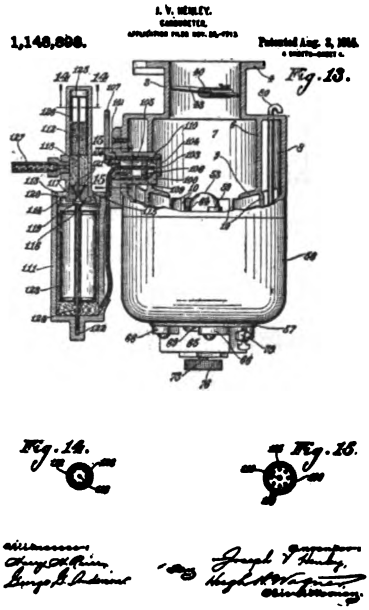
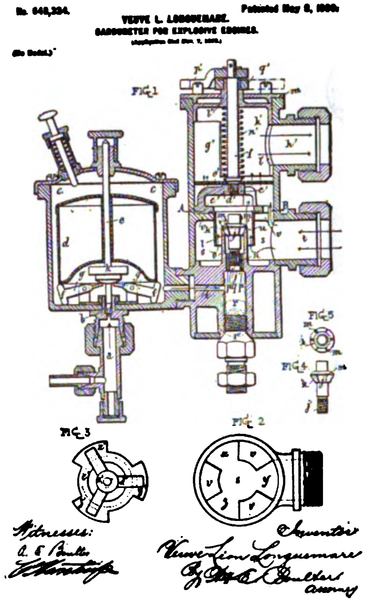


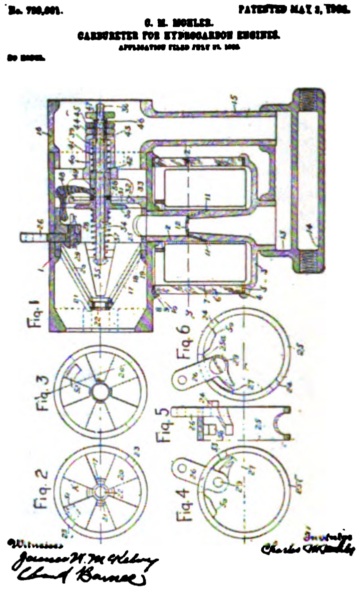
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 6.

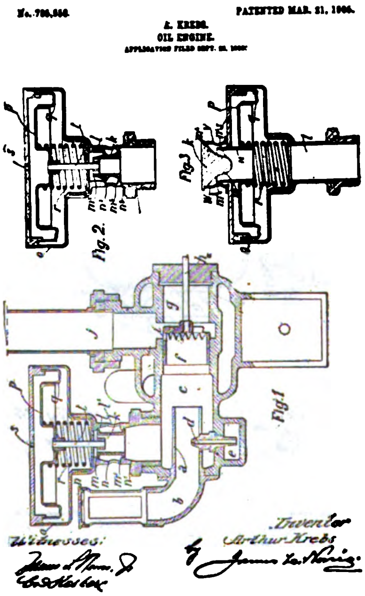

J. T. ATHERTON.
CARBURETER.
Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
Witnesses:
Inventor:

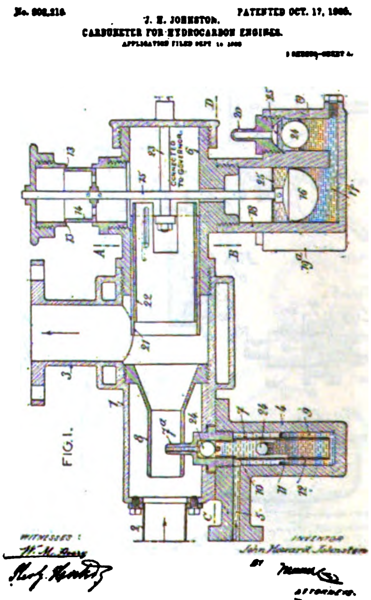

J. V. HENLEY.
CARBURETER.
1,148,898.
Patented Aug. 3, 1915.
Fig. 7.
Fig. 8.
Fig. 9.
Fig. 10.
Fig. 11.
Fig. 12.


J. V. HENLEY.
CARBURETER.
1,148,898.
Patented Aug. 3, 1915.
Fig. 13.
Fig. 14.
Fig. 15.


CARBURETER FOR EXPLOSIVE ENGINES.
FIG. 1
FIG. 2
FIG. 3
FIG. 4
FIG. 5
Witnesses:
Inventor
Attorney


C. M. MOHLER.
CARBURETER FOR HYDROCARBON ENGINES.
Fig. 1
Fig. 2
Fig. 3
Fig. 4
Fig. 5
Fig. 6
Witnesses


PATENTED MAR. 21, 1906.
OIL ENGINE.
Fig. 1
Fig. 2.
Fig. 3
Witnesses:
Inventor
Arthur Krebs


PATENTED OCT. 17, 1905.
J. H. JOHNSTON.
CARBURETER FOR HYDROCARBON ENGINES.
FIG. 1.
WITNESSES:
INVENTOR
ATTORNEYS.

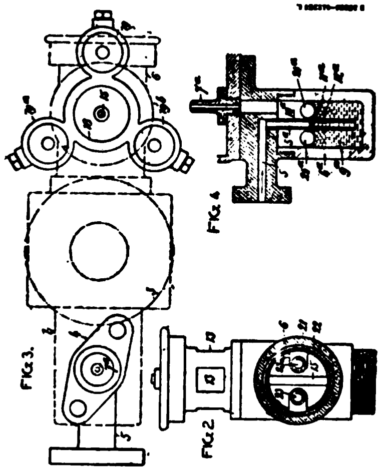
No. [illegible] PATENTED OCT. 17, 1905.

J. H. JOHNSTON.

CARBURETER FOR HYDROCARBON ENGINES.

APPLICATION FILED SEPT. 14, [illegible].

[illegible] SHEETS—SHEET [illegible]



Witnesses [illegible]

Inventor John Howard Johnston by [illegible] Attorneys

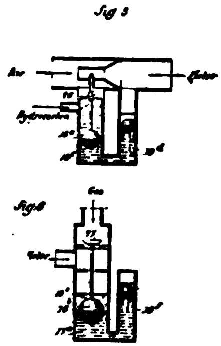
No. [illegible] PATENTED OCT. 17, 1905.

J. H. JOHNSTON.

CARBURETER FOR HYDROCARBON ENGINES.

APPLICATION FILED SEPT. [illegible]

[illegible] SHEETS—SHEET [illegible]



Witnesses [illegible]

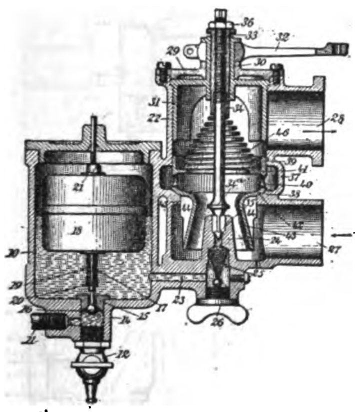
Inventor John Howard Johnston by [illegible] Attorneys

No. [illegible] PATENTED JAN. 23, 1906.

J. McINTOSH.

CARBURETER.

APPLICATION FILED OCT. [illegible]



Witnesses [illegible]

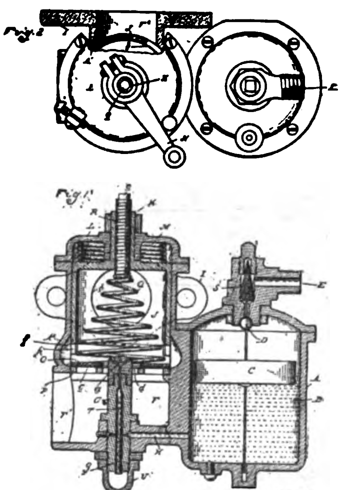
Inventor James McIntosh by [illegible] Attorneys

No. [illegible] PATENTED SEPT. 25, 1906.

H. E. COFFIN.

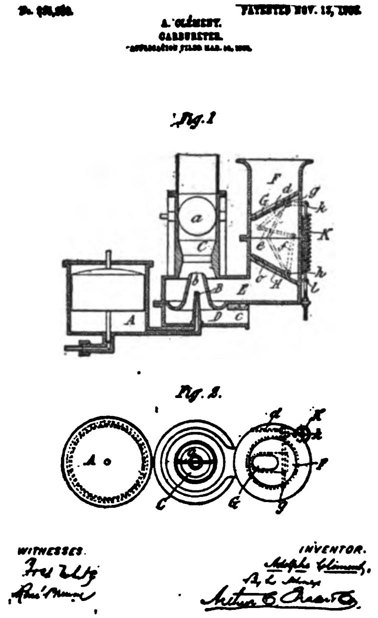
CARBURETER FOR HYDROCARBON ENGINES.

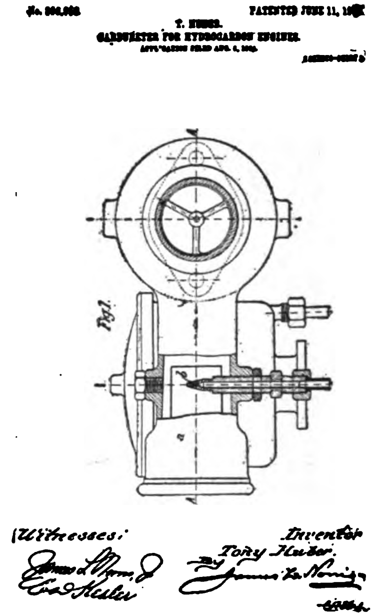
APPLICATION FILED OCT. 11, [illegible].

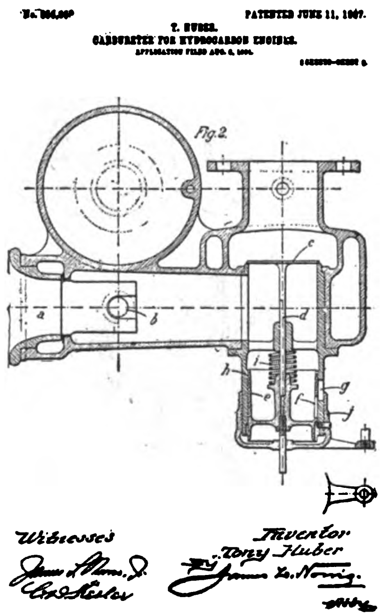


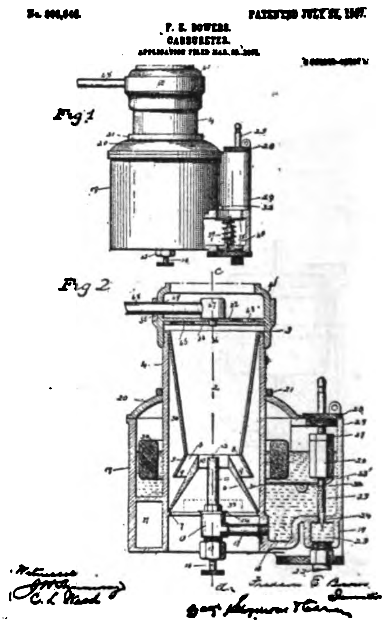
Witnesses [illegible]

Inventor Howard E. Coffin by James Whittemore Atty.

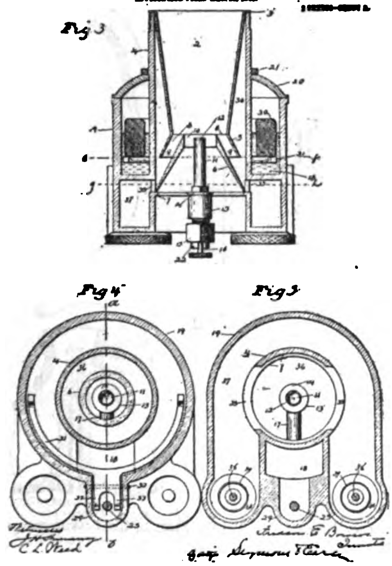

A. CLÉMENT.
CARBURETER.
Fig.1
Fig.2
WITNESSES.
INVENTOR.


T. HUBER.
CARBURETER FOR HYDROCARBON ENGINES.
PATENTED JUNE 11, 1907.
Fig.1.
Witnesses:
Inventor
Tony Huber.

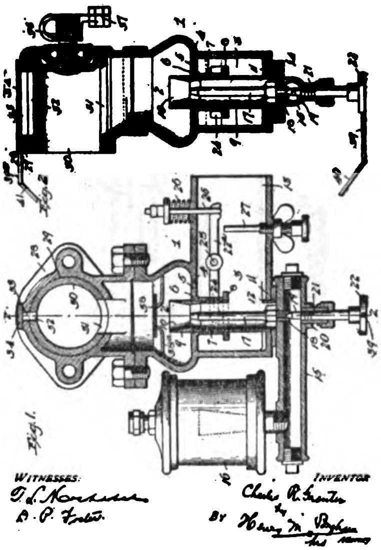

T. HUBER.
CARBURETER FOR HYDROCARBON ENGINES.
PATENTED JUNE 11, 1907.
Fig.2.
Witnesses
Inventor
Tony Huber


F. E. BOWERS.
CARBURETER.
Fig.1
Fig.2

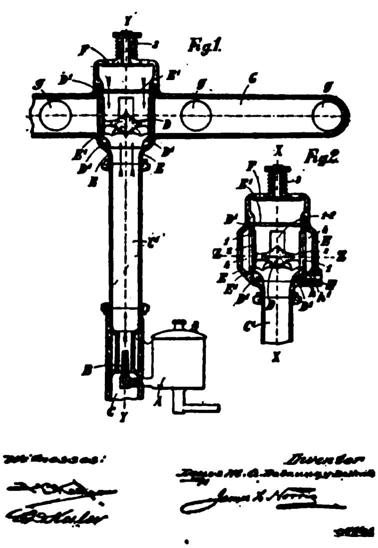
No. [illegible] PATENTED JULY [illegible], 1907.
F. E. BOWERS.
CARBURETER.
APPLICATION FILED [illegible]



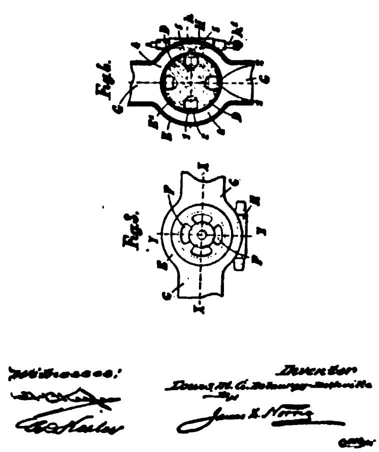
No. [illegible] PATENTED MAY 26, 1908.
C. R. GREUTER.
CARBURETER.
APPLICATION FILED [illegible]



No. [illegible] PATENTED MAY 26, 1908.
L. M. G. DELAUNAY-BELLEVILLE.
AUTOMATIC CARBURETER FOR EXPLOSIVE MOTORS.
APPLICATION FILED SEPT. [illegible]

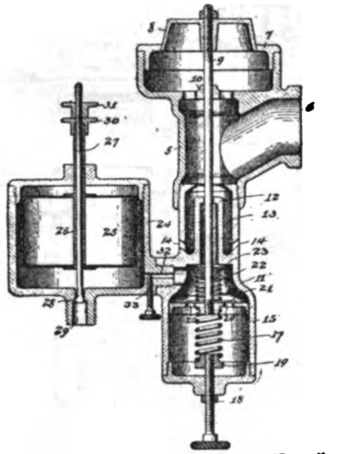


No. [illegible] PATENTED MAY 26, 1908.
L. M. G. DELAUNAY-BELLEVILLE.
AUTOMATIC CARBURETER FOR EXPLOSIVE MOTORS.
APPLICATION FILED SEPT. [illegible]



W. A. DALEY.

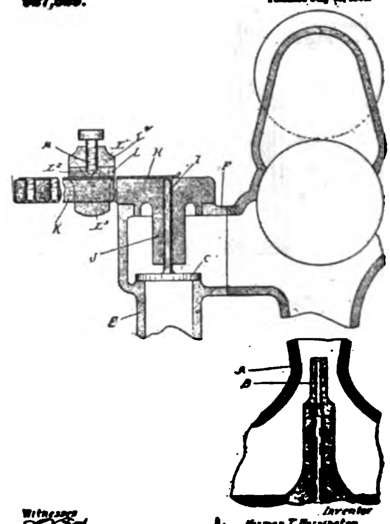
912,069. Patented Feb. 9, 1909.



H. T. HARRINGTON.

CARBURETER.

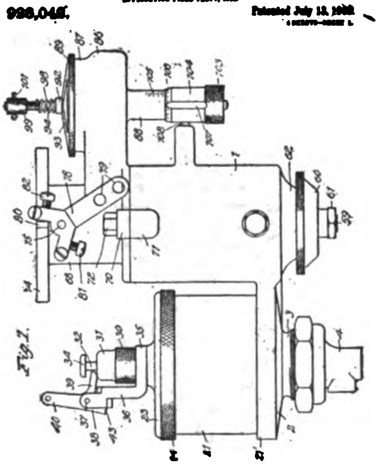
927,589. Patented July 13, 1909.



J. S. GOLDBERG.

CARBURETER.

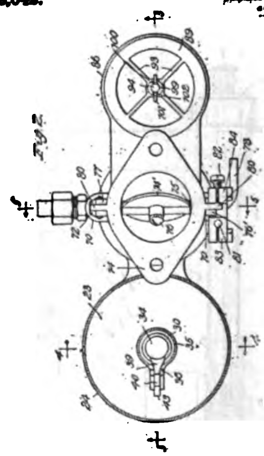
928,042. Patented July 13, 1909.



J. S. GOLDBERG.

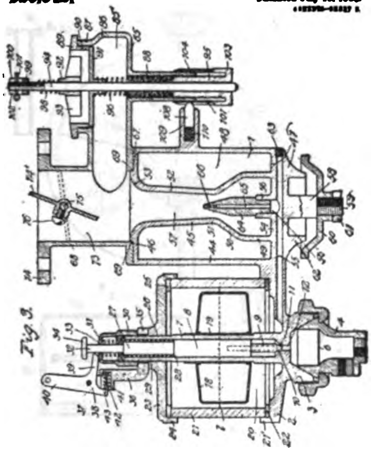
CARBURETER.

928,042. Patented July 13, 1909.



J. S. GOLDBERG.
CARBURETER.

928,049. Patented July 13, 1909.

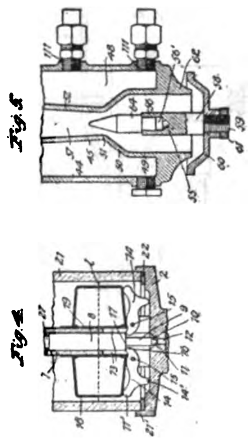


Witnesses:
Leonard W. Novander
George C. Hyland

Inventor
John S. Goldberg
By Brown & Williams
Attorneys.

J. S. GOLDBERG.
CARBURETER.

928,049. Patented July 13, 1909.

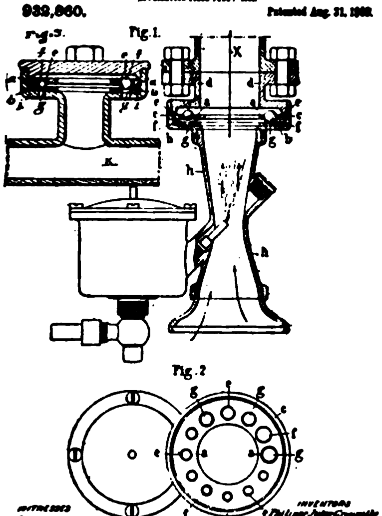


Witnesses:
Leonard W. Novander
Charles J. Schmidt

Inventor
John S. Goldberg
By Brown & Williams
Attorneys

P. J. GROUVELLE & E. H. ARQUEMBOURG.
CARBURETER FOR INTERNAL COMBUSTION ENGINES.

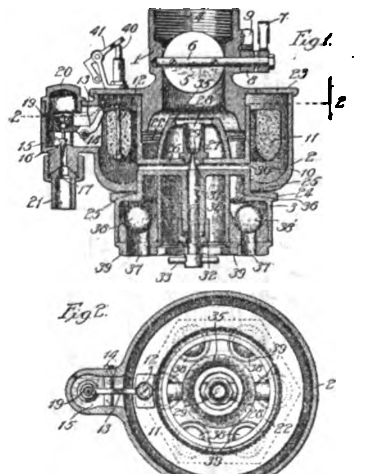
932,860. Patented Aug. 31, 1909.



WITNESSES
Philippe Jules Grouvelle
Emile Henri Arquembourg
BY Munn & Co
ATTORNEYS

F. L. KINGSTON.
CARBURETER.

974,076. Patented Oct. 25, 1910.

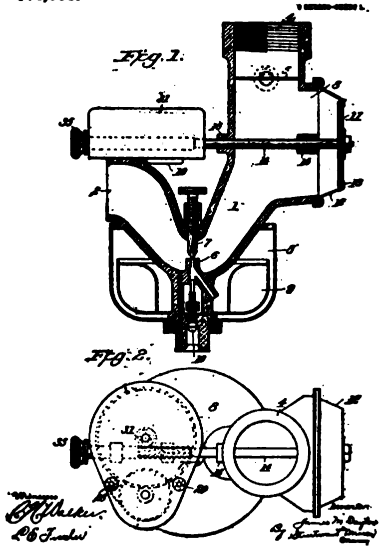


Witnesses:
John Enders

Inventor
Frank L. Kingston
By McMeen & Miller
Attys.

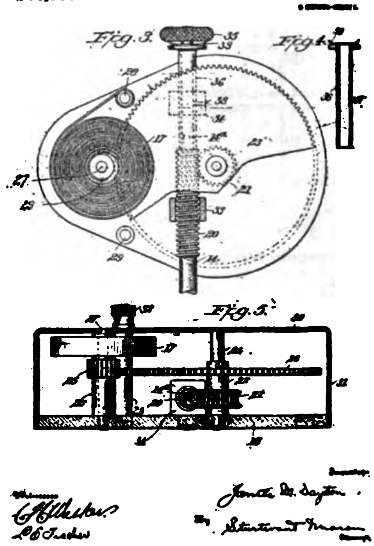
J. M. DAYTON.
AIR CONTROLLING MECHANISM FOR CARBURETERS.
APPLICATION FILED NOV. 2, 1907.

976,558. Patented Nov. 22, 1910.



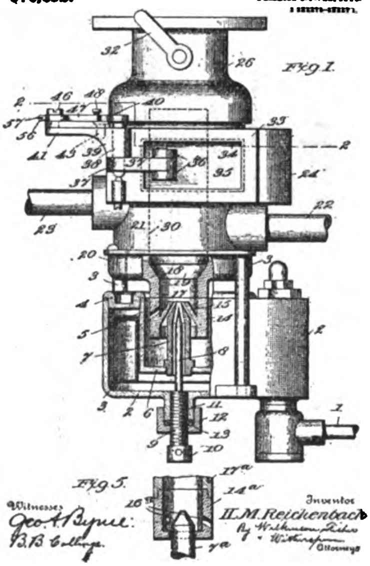
J. M. DAYTON.
AIR CONTROLLING MECHANISM FOR CARBURETERS.
APPLICATION FILED NOV. 2, 1907.

976,558. Patented Nov. 22, 1910.



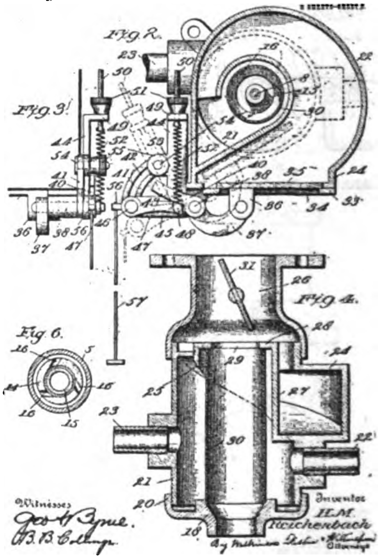
H. M. REICHENBACH.
CARBURETER.
APPLICATION FILED APR. 1, 1910.

976,692. Patented Nov. 22, 1910.



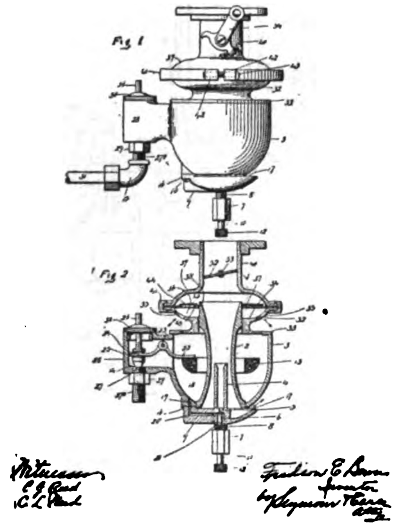
H. M. REICHENBACH.
CARBURETER.
APPLICATION FILED APR. 1, 1910.

976,692. Patented Nov. 22, 1910.



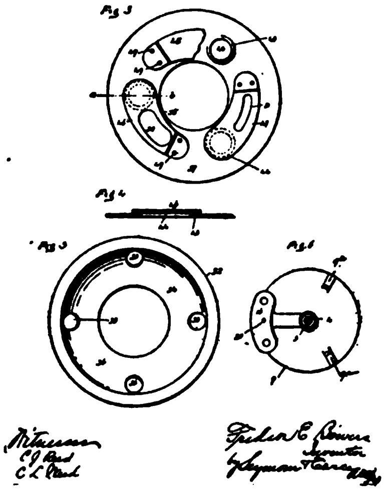
F. S. BOWERS.
CARBURETER.
APPLICATION FILED JAN. 11, 1909.

997,233. Patented July 4, 1911.
2 SHEETS—SHEET 1.



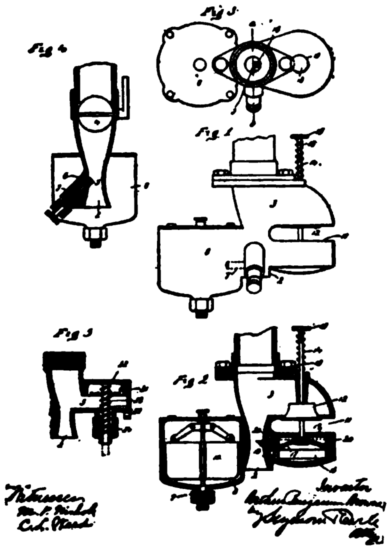
F. S. BOWERS.
CARBURETER.
APPLICATION FILED JAN. 11, 1909.

997,233. Patented July 4, 1911.
2 SHEETS—SHEET 2.



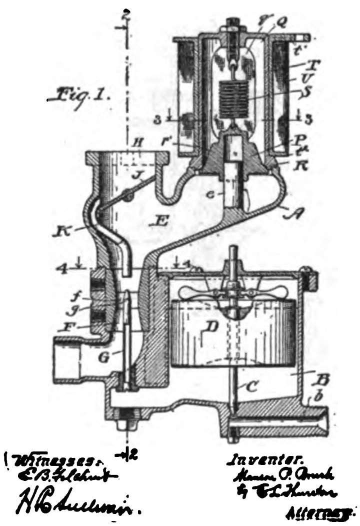
A. B. BROWNE.
CARBURETER.
APPLICATION FILED APR. 12, 1914.

Reissued Aug. 4, 1914. 13,784.



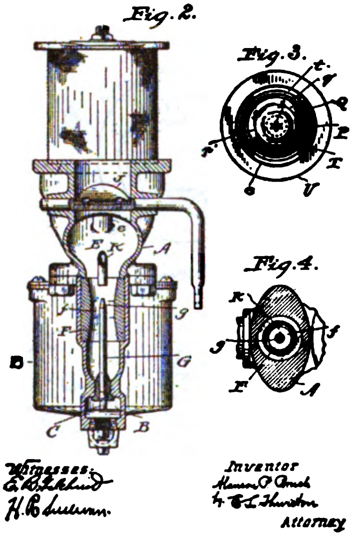
A. P. BRUSH.
CARBURETER.
APPLICATION FILED JAN. 12, 1910.

1,069,671. Patented Aug. 12, 1913.
2 SHEETS—SHEET 1.



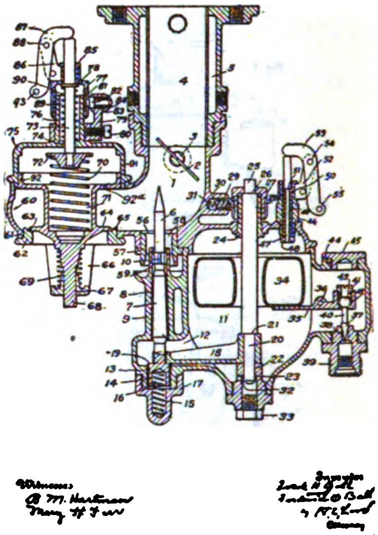
A. P. [illegible]
CARBURETER.
APPLICATION FILED [illegible]

1,069,671. Patented Aug. 12, 1913.



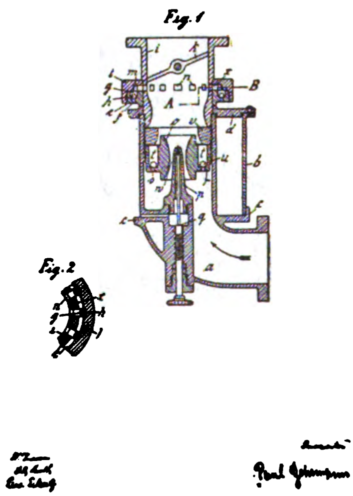
P. E. & F. O. BALL.
CARBURETER.
APPLICATION FILED [illegible]

1,071,858. Patented Sept. 2, 1913.



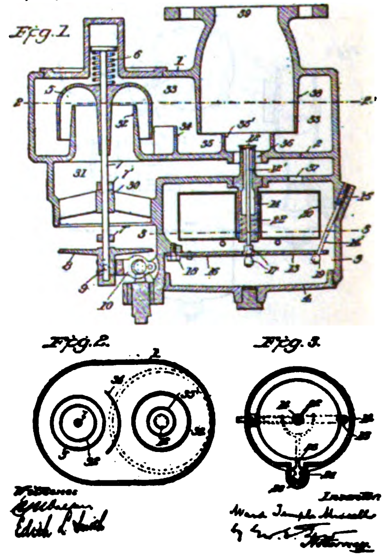
P. OEHRMANN.
CARBURETER.
APPLICATION FILED FEB. [illegible]

1,086,287. Patented Feb. 3, 1914.



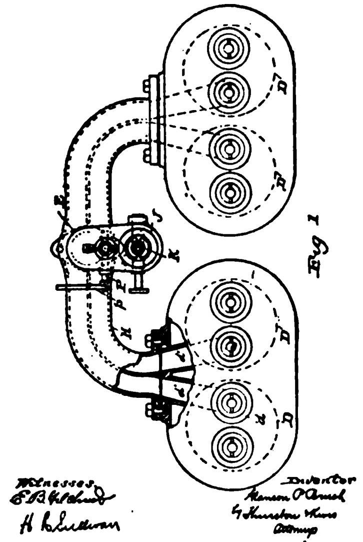
W. T. [illegible]
CARBURETER.
APPLICATION FILED APR. 10, [illegible]

1,092,989. Patented Apr. 7, 1914.



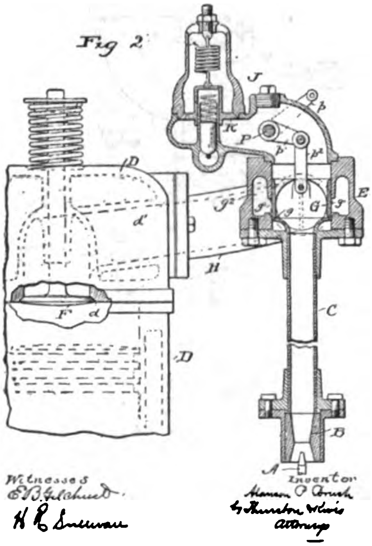
A. P. BRUSH
MIXTURE SUPPLYING APPARATUS FOR INTERNAL COMBUSTION ENGINES.
APPLICATION FILED MAY 8, 1911.

1,112,257. Patented Sept. 29, 1914.



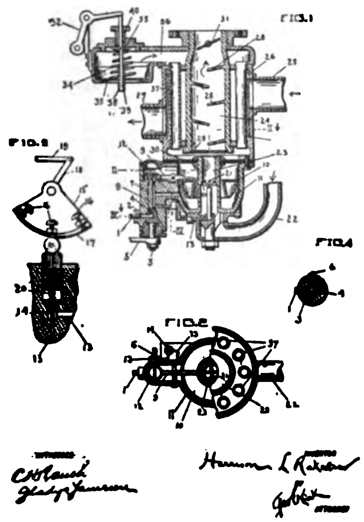
A. P. BRUSH
MIXTURE SUPPLYING APPARATUS FOR INTERNAL COMBUSTION ENGINES.
APPLICATION FILED MAY 8, 1911.

1,112,257. Patented Sept. 29, 1914.



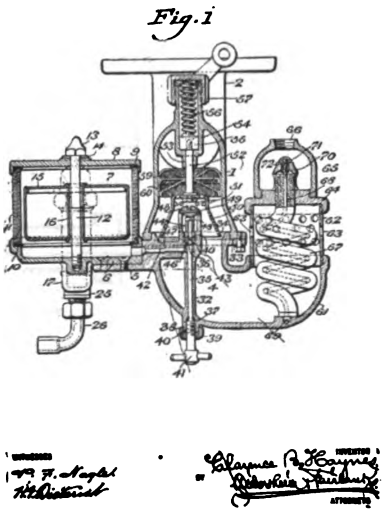
H. L. RAKESTRAW
CARBURETER.

1,140,064. Patented May 18, 1915.



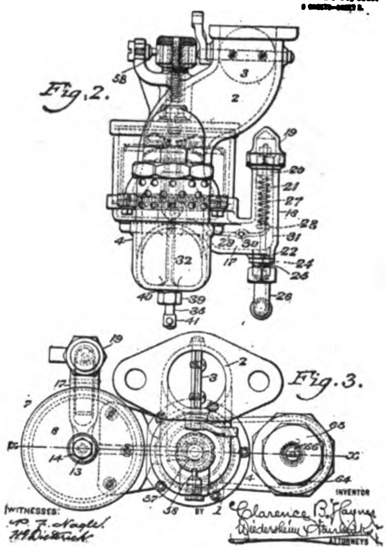
C. B. HAYNES.
CARBURETER.

1,143,961. Patented June 22, 1915.



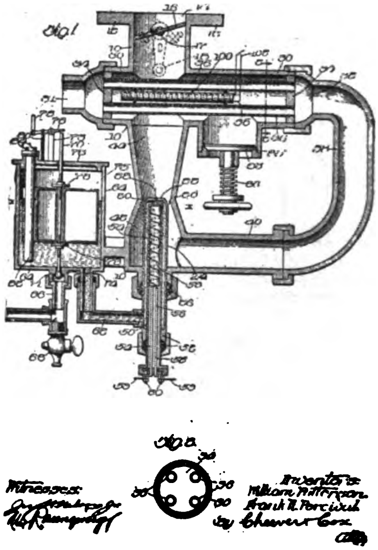
C. B. HAYNES.
CARBURETER.
APPLICATION FILED [illegible]

1,143,981. Patented June 22, 1915.
2 SHEETS—SHEET 2.



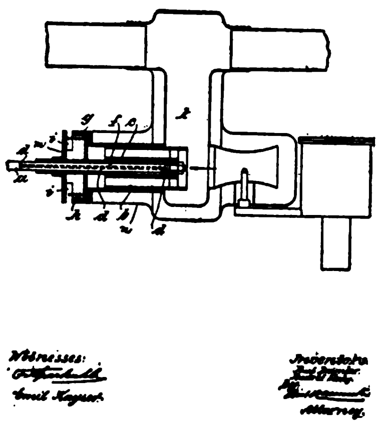
F. H. PERCIVAL & W. PATTERSON.
KEROSENE CARBURETER.
APPLICATION FILED JULY 8, 1913.

1,150,619. Patented Aug. 17, 1915.



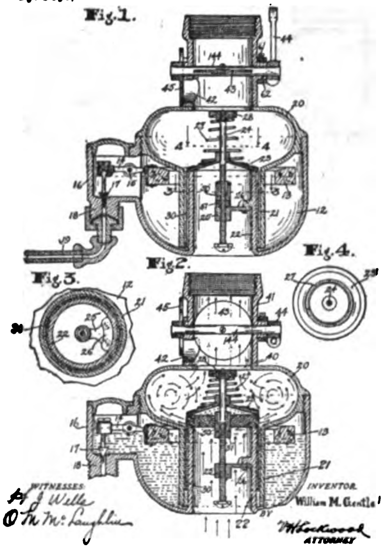
P. DAIMLER & R. SLABY.
THROTTLE VALVE FOR CARBURETERS.
APPLICATION FILED JAN. 14, 1915.

1,162,576. Patented Nov. 30, 1915.

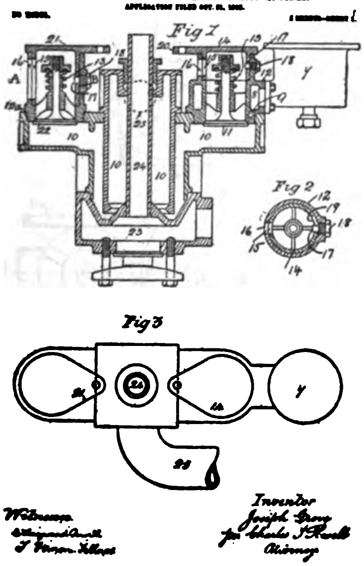


W. M. GENTLE.
CARBURETER.

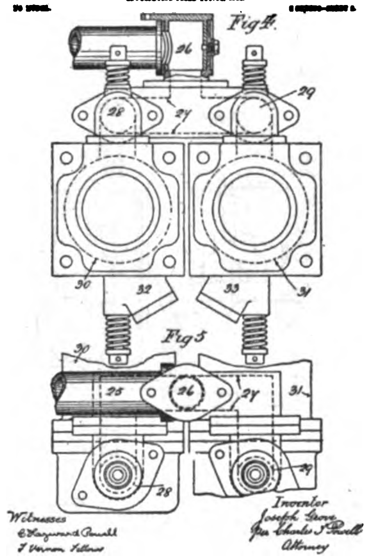
1,060,545. Patented Apr. 29, 1913.



No. 762,707. PATENTED JUNE 14, 1904.
J. GROVE.
CARBURETER FOR INTERNAL COMBUSTION ENGINES.
APPLICATION FILED OCT. 31, 1903.
NO MODEL. 2 SHEETS—SHEET 1.



No. 762,707. PATENTED JUNE 14, 1904.
J. GROVE.
CARBURETER FOR INTERNAL COMBUSTION ENGINES.
APPLICATION FILED OCT. 31, 1903.
NO MODEL. 2 SHEETS—SHEET 2.

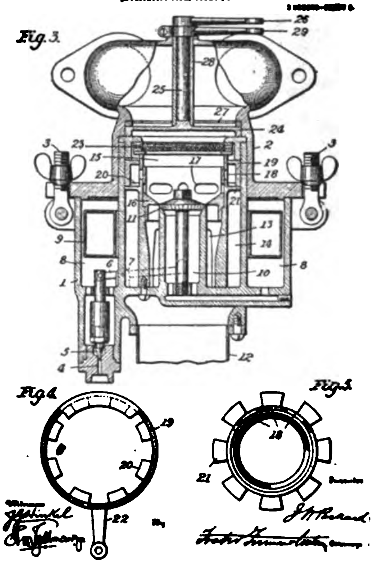


PATENTED DEC. 12, 1905.

J. W. PACKARD.

MIXER AND VAPORIZER FOR HYDROCARBON ENGINES.

APPLICATION FILED JUNE 20, 1905.

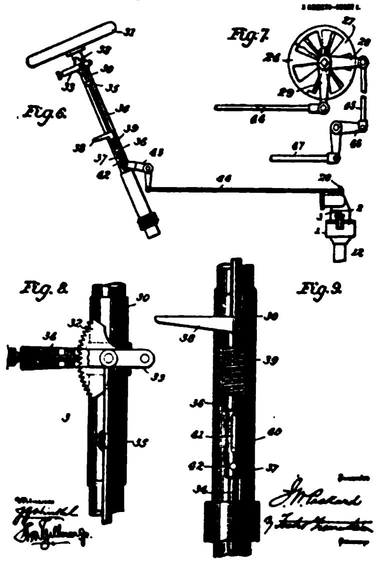


PATENTED DEC. 12, 1905.

J. W. PACKARD.

MIXER AND VAPORIZER FOR HYDROCARBON ENGINES.

APPLICATION FILED JUNE 20, 1905.

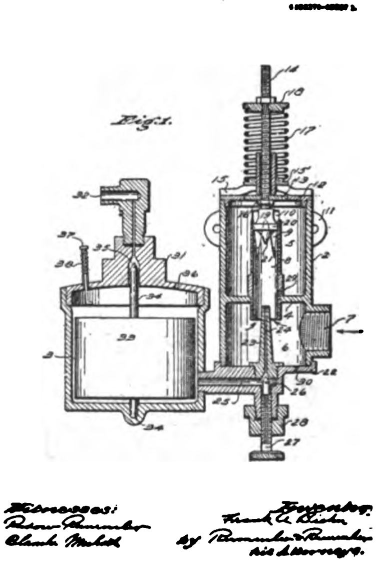


No. 790,173. PATENTED MAY 16, 1905.

F. A. BIEHN.

CARBURETER FOR EXPLOSIVE ENGINES.

APPLICATION FILED MAR. 3, 1905.

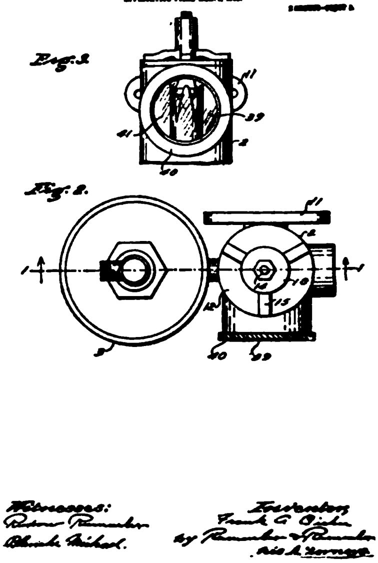


No. 790,173. PATENTED MAY 16, 1905.

F. A. BIEHN.

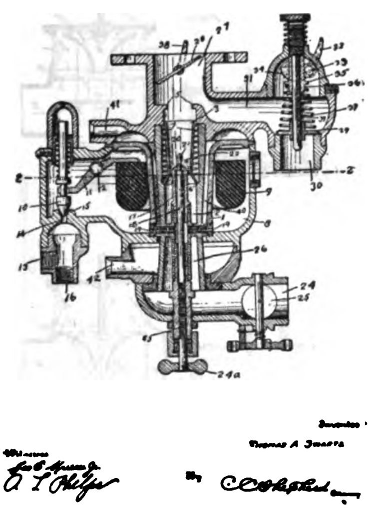
CARBURETER FOR EXPLOSIVE ENGINES.

APPLICATION FILED MAR. 3, 1905.



CARBURETER.

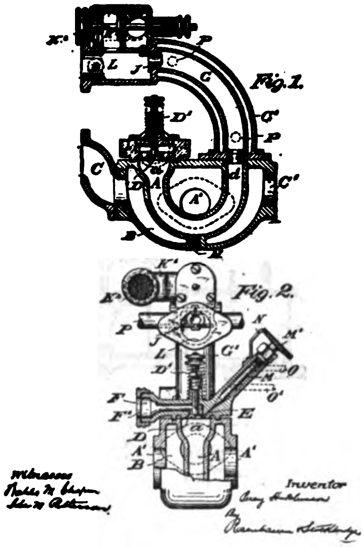
1,168,187. Patented May 16, 1916.



F. HUTCHINSON.

CARBURETER.

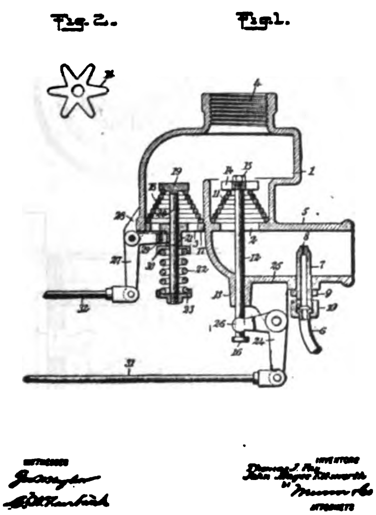
1,186,675. Patented Apr. 20, 1915.



T. J. FAY & J. M. ELLSWORTH.

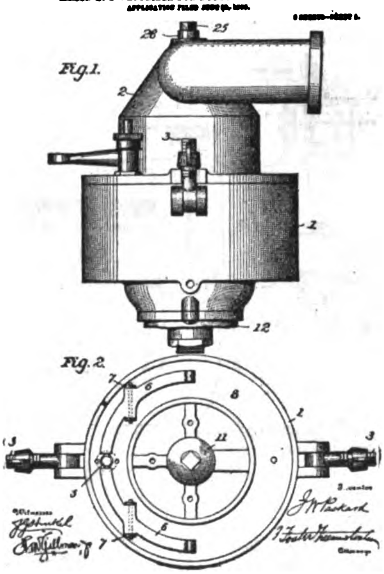
CARBURETER.

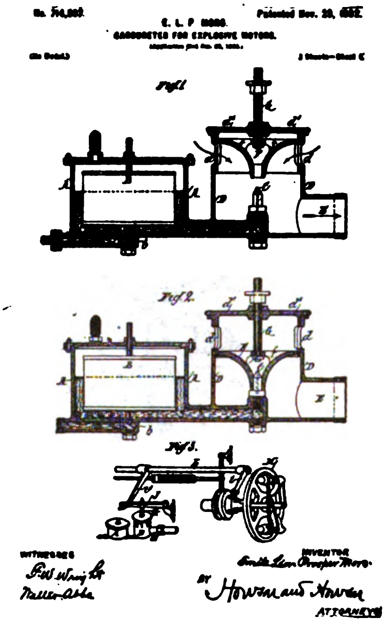
960,080. Patented May 31, 1910.

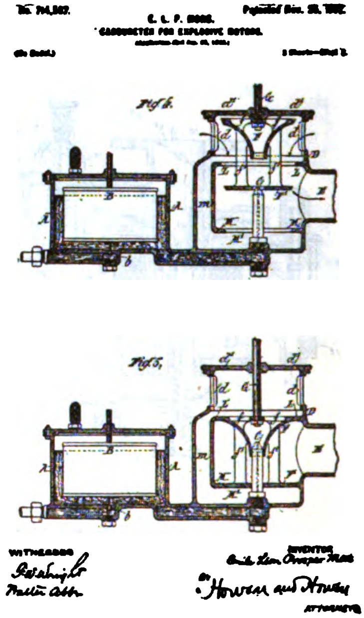


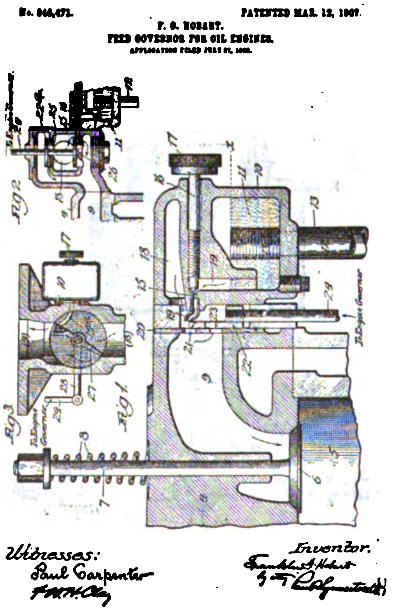
J. W. PACKARD.

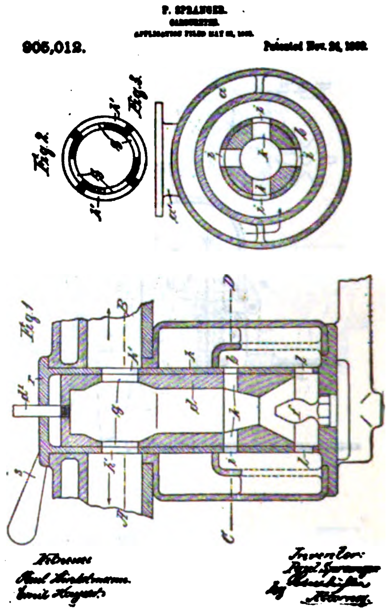
MIXER AND VAPORIZER FOR HYDROCARBON ENGINES.

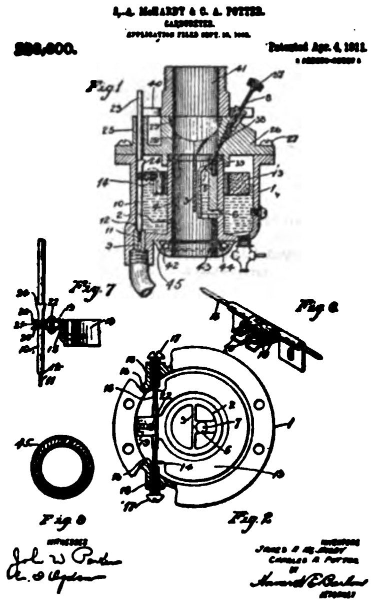


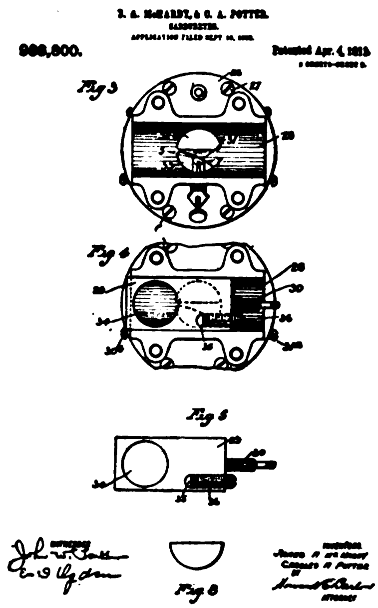

C. L. P. MOORE.
CARBURETER FOR EXPLOSIVE MOTORS.
Fig. 1
Fig. 2
Fig. 3
WITNESSES
INVENTOR
ATTORNEYS

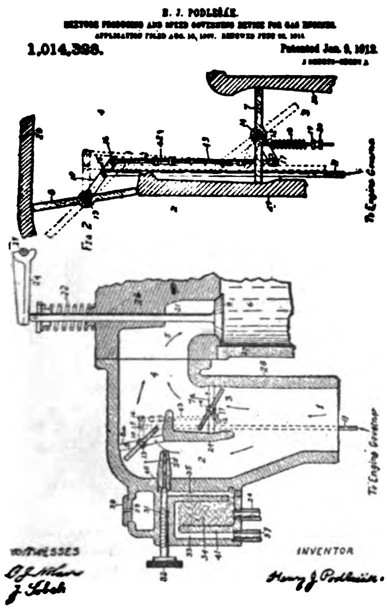

CARBURETER FOR EXPLOSIVE MOTORS.
Fig. 4
Fig. 5
WITNESSES
INVENTOR
ATTORNEYS


PATENTED MAR. 12, 1907.
F. G. HOBART.
FEED GOVERNOR FOR OIL ENGINES.
Fig. 1
Fig. 2
Fig. 3
Witnesses:
Paul Carpenter
Inventor.


906,012.
CARBURETER.
Fig. 1
Fig. 2
Inventor:


CARBURETER.
Patented Apr. 4, 1911.
Fig 1
Fig 7
Fig 6
Fig 2
Fig 9


CARBURETER.
988,800.
Patented Apr. 4, 1911.
Fig 3
Fig 4
Fig 5
Fig 8


Patented Jan. 2, 1912.
Fig 2
To Engine Governor
WITNESSES
INVENTOR

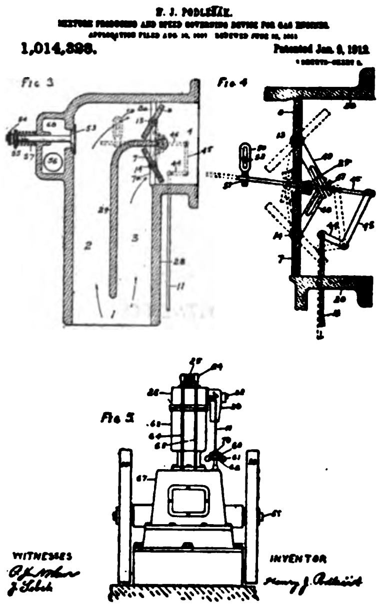
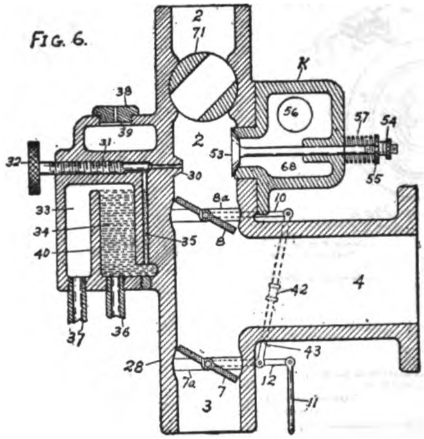


Fig 3
Fig 4
Fig 5
WITNESSES
INVENTOR

H. J. PODLESAK.
MIXTURE PRODUCING AND SPEED GOVERNING DEVICE FOR GAS ENGINES.
APPLICATION FILED AUG. 12, 1907. RENEWED JUNE 22, 1911.

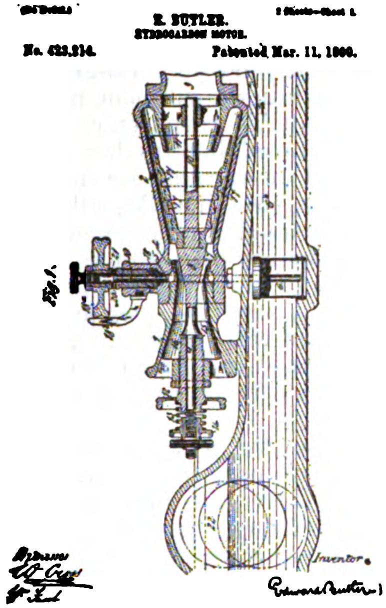
1,014,328. Patented Jan. 9, 1912.
3 SHEETS—SHEET 3.

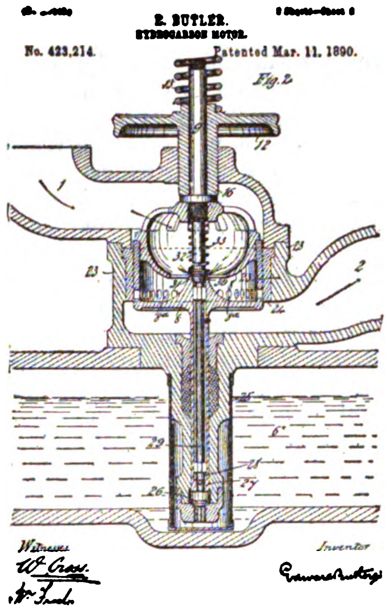
FIG. 6.

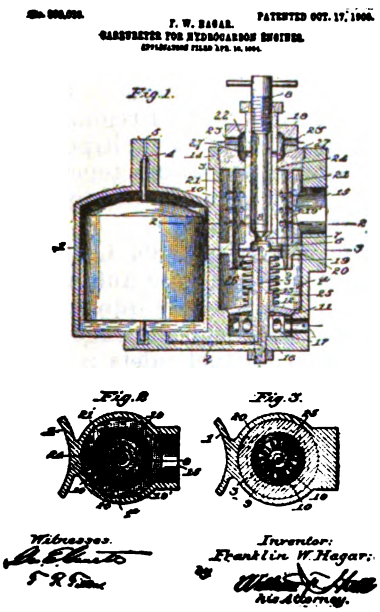


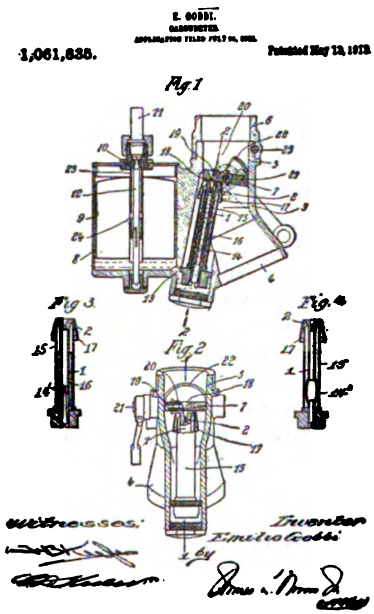
WITNESSES
James A. Tollar
Emil Podlesak

INVENTOR
Henry J. Podlesak


E. BUTLER.
HYDROCARBON MOTOR.
No. 423,214.
Patented Mar. 11, 1890.
Fig. 1.
Inventor.


E. BUTLER.
HYDROCARBON MOTOR.
No. 423,214.
Patented Mar. 11, 1890.
Fig. 2
Witnesses
Inventor


F. W. HAGAR.
CARBURETER FOR HYDROCARBON ENGINES.
Fig. 1.
Fig. 2
Fig. 3.
Witnesses.
Inventor:
Franklin W. Hagar;
his Attorney.


E. GOBBI.
CARBURETER.
1,061,835.
Fig. 1
Fig. 2
Fig. 3.
Fig. 4
Witnesses:
Inventor
Emilio Gobbi
by

Class 9—carburetors, proportioning flow, aspirating, multiple fixed fuel inlets, single air inlet with regulating valve.—As the proportionality between air and fuel for every fixed fuel inlet in a fixed air inlet is constant within some range of flow rates peculiar to the particular arrangement in question, one more or less obvious way of avoiding the necessity for compensation beyond this range is to limit the action to the range itself by providing a sufficient number of such operating units—in short the multiple carburetor. Such multiple carburetors have already been examined, but another sort or series of multiple carburetors can be based on variable air inlets as on fixed, and with some advantages. This class includes all those having a series of fixed fuel inlets with any number of air inlets provided with air area regulating valves. The common groups of arrangements constitute each a subclass, two of these being concerned with a single air valve, opening of which brings the fuel jets successively into action, the standpipe associated with an air inlet valve another, the two jet, high and low speed or idling, and main, used with air inlet valves, makes still another, and finally the tilting fuel chamber, a last group.

A single example will serve to illustrate the general class, not definitely belonging to the subclasses, that on page 329. (1,177,538, Mar. 28, 1916, Roberts.) Here a series of three fuel inlets is placed in a cylindrical passage with valved partitions each side of each jet, the valves being linked together, so the throttle for the first jet is the air inlet for the second. While each nozzle is located at the same height above its float chamber level, each successive one is acted on by a different vacuum.

Subclass 9.1—Fuel inlets act progressively with opening of automatic air inlet regulating valve.—From one point of view there would be no difference between this and the case of one variable fuel inlet or one multiported fixed fuel inlet associated with variable air inlet, but there is a real difference, because here there is no fuel-regulating valve, and the several fuel inlets are not equivalent to a multiported single inlet because all the orifices of the latter always work together, whereas in the present case there are times when all are working and other times when perhaps only one is in action.

Four fuel inlets are arranged on page 330 (1,006,130, Oct. 17, 1911, Riotte), to be just out of the path of a swing-gate automatic air valve across the air inlet, and are brought successively into action by the air-valve movements; those nozzles lying inside its edge discharge fuel, those outside do not. A series of 10 fuel inlets is provided on pages 330 and 331. (1,011,960, Dec. 19, 1911, Ionides.) These are arranged along the top edge of a longitudinal slot cut in a cylindrical casing, which is traversed by a vacuum-controlled piston valve. The length of slot exposed to air flow across it determines the number of fuel inlets acted on by the air velocity head vacuum inducing fuel flow. An almost identical plan with a variation of some structural details is shown on pages 331 and 332. (1,119,076, Dec. 1, 1914, Freyl.) A group of four nozzles arranged radially around the seat of an air valve at different heights is shown on page 332. (1,130,474, Mar. 2, 1915, Brush.)

Subclass 9.2—Fuel inlets act progressively with opening of throttle-controlled air inlet regulating valve.—This subclass is similar to the last except for the control of the air valve, which is here directly by

the throttle or is itself the throttle. As engines may operate at a considerable speed range for a given throttle position, so does the throttle seem to be an indirect means of total air and active fuel inlet control, by no means as primary a variable as the vacuum that itself is fixed by or fixes flow. It would seem, therefore, that this class contributes less to the solution of the problem of proportionate flow than the last, but as one is convertible into the other by well-known means the cases of the class are worth study with that fact in view.

One fairly early case, considering the youth of the whole art, is that on page 333 (858,437, July 2, 1907, Brooke), which illustrates a cylindrical valve acting at the same time as air inlet and throttle as it moves longitudinally and uncovers and exposes to the vacuum of air flow, three fuel inlets in succession. Seven fuel inlets are successively brought into action by the cylindrical slide, serving as both throttle and air valve in the arrangement on page 333. (881,279, Mar. 10, 1908, Allen.) Here the orifices are placed well in front of the slide and fuel flow is induced solely by air velocity head vacuum, so as the air flow does or does not sweep an orifice, that orifice discharges fuel or does not, and the amount of discharge of any one or all that are exposed varies with the velocity of air past it, but, of course, not necessarily in direct proportion. The iris form of air valve or throttle reappears once more on pages 333 and 334 (881,800, Mar. 10, 1908, Horstmann), this time the continually enlarging circle of air entrance exposes to the action of air velocity four fuel nozzles at different distances from the center. Each in turn, they discharge under the air velocity head vacuum influence, the direction of air flow being parallel to that of fuel flow instead of crosswise as in the last case.

Three fuel nozzles uncovered in succession by a cylindrical valve serving as throttle receive air partly from a fixed and partly from an automatic inlet, which thus impose a vacuum due to entrance resistance in addition to the velocity head vacuum, but the former must be kept low enough so that the nozzles screened by the valve do not discharge. This is illustrated on page 334. (1,073,179, Sept. 16, 1913, Sprung.) An interesting special form is shown on page 335 (1,089,524, Mar. 10, 1914, Barrett & Wilson), where a straight row of fuel inlets in a rectangular air passage is swept by a rotating throttle disk having a rectangular hole, the angle between the long axes of the two rectangles determines the area of air passage exposed and the length of the fuel nozzle line. A rotating barrel throttle with two slots, one, straight sided and parallel, acting as throttle and the other, inclined, acting to control the lengthened area of the air inlet and the number of fuel inlets exposed, is shown on page 335. (1,094,674, Apr. 28, 1914, Miller & Adamson.) A later form provided with a second air valve of the swing type, controlling the distribution of the air on the two sides of the line of fuel inlets, also operated with the throttle and arranged with two float chambers to use two fuels, the more volatile one acting only on the low-speed end of the nozzle row for starting and the less volatile feeding all the rest of the nozzles, is shown on pages 335 and 336. (1,183,221, May 16, 1916, Miller & Adamson.)

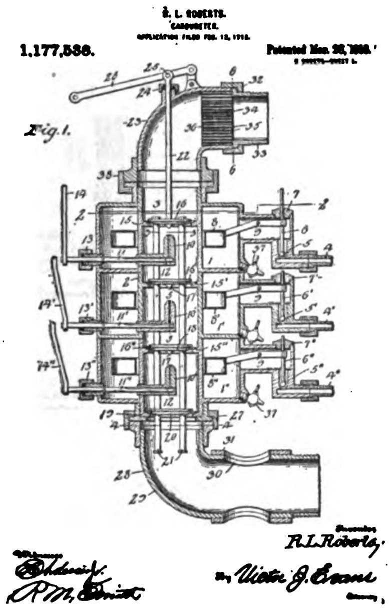
Subclass 9.3—Standpipe.—This subclass is similar to the standpipe subclass already reviewed, except that the latter received its air through fixed inlets, whereas in the present case the air enters through regulating air valves, which prevent the vacuum from in-

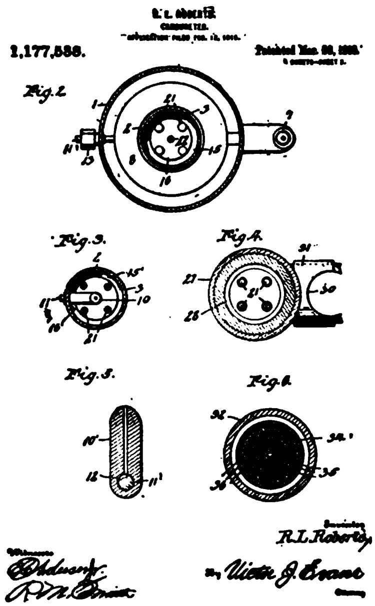
creasing so much with the air flow increase, and thus permitting of shorter standpipes. In the first case, on page 337 (1,130,700, Mar. 9, 1915, Bennett), air enters partly through a fixed and partly through an automatic valved inlet to a series of fuel outlets at different heights. Each of these is formed in a peculiar way, two thin metal sheets, sector shaped, fastened together on the radial but free on the circular edges, surround each fuel inlet, the circular edges pointing up at different heights. Air flow presses these together as it passes and the fuel discharges successively from the edges of the higher ones as flow increases, always into high velocity air. A curious form of this class is that on page 337 (1,147,337, July 20, 1915, Muir), provided with one nozzle fixed in position and several others at different levels in the body of an automatic air valve, gravity closed. As the air valve lifts a series of fuel nozzles are brought into action at different heights above the float level and in different vacuum positions; the fixed nozzle comes in only after the air valve has stopped rising and the vacuum still continues to increase; it therefore is a sort of high-speed supplementary jet.

Subclass 9.4—Two fuel inlets, one main and one idling.—Air enters through a special swing form of automatic valve, on page 338 (825,499, July 10, 1906, Sturtevant & Sturtevant), and fuel at the constantly narrowest part of the air inlet, so its flow is due to air velocity primarily. A separate fuel inlet is arranged in the throttle for idling. A single damper valve acting both as air valve and throttle is associated with two fuel inlets in front of it, on page 338 (1,016,108, Jan. 30, 1912, Steinbrenner), in such a way as to bring only one into action when the throttle is closed, while both act at more open positions if, of course, the velocity is high enough. A different and later disposition of two fuel inlets with respect to a damper valve, acting as throttle and air valve, whereby one only acts at idling and both for wider open throttle position is shown on page 338. (1,147,940, July 27, 1915, Griffin.)

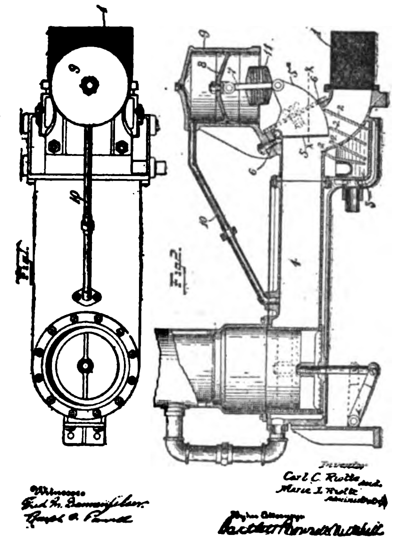
Subclass 9.5—Tilting fuel chamber, radially disposed fuel inlets.—This is a sort of complement or inverse of the standpipe, where on increased air flow the resulting vacuum lifts the fuel to successively higher orifices, while here the nozzles are successively depressed in regions of the same or rising vacuum, but usually by the throttle or air valve.

A closed float chamber supported so as to rotate on two pins and lying wholly within the air passage is provided with a row of fuel orifices at different heights with reference to a lateral plane, so that they come successively within the sweeping action of the air current entering between the float chamber body acting as air valve and the casing, is the combination shown on page 339. (989,307, Apr. 11, 1911, Simmons.) Seven radial tubes at different angles on a constant level chamber formed in a valve spindle rotate with the latter and are brought into action by coming into the air stream successively as the valve opens. At the same time their flow varies, because of the changing liquid head, according to the arrangement on page 339. (1,073,577, Sept. 30, 1913, Smith.)

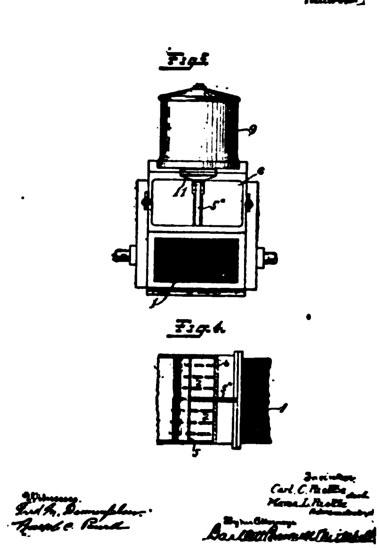

1,177,538.
Fig. 1.
R. L. Roberts,
Victor J. Evans


1,177,538.
Fig. 2
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 6.
R. L. Roberts,
Victor J. Evans

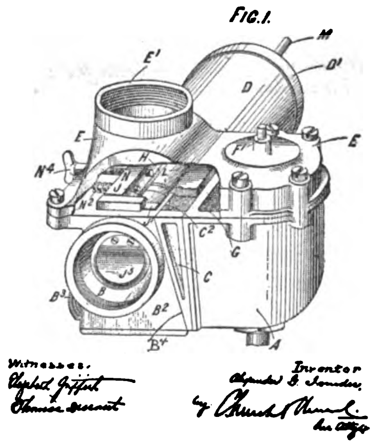
1,006,130. C. C. RIOTTE, DEC'D. VAPORIZER. Patented Oct. 17, 1911.



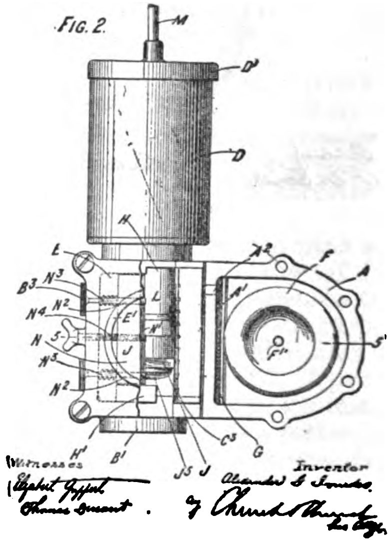
1,006,130. C. C. RIOTTE, DEC'D. VAPORIZER. Patented Oct. 17, 1911.



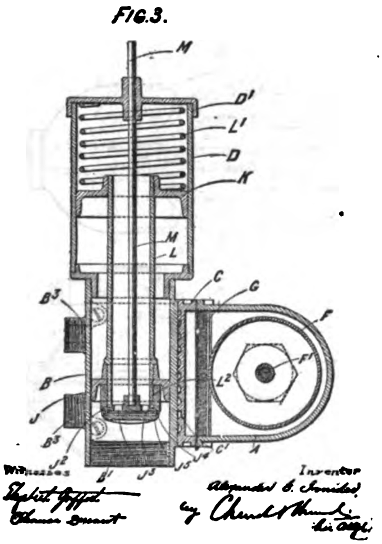
1,011,960. A. G. IONIDES. CARBURETER. Patented Dec. 19, 1911.



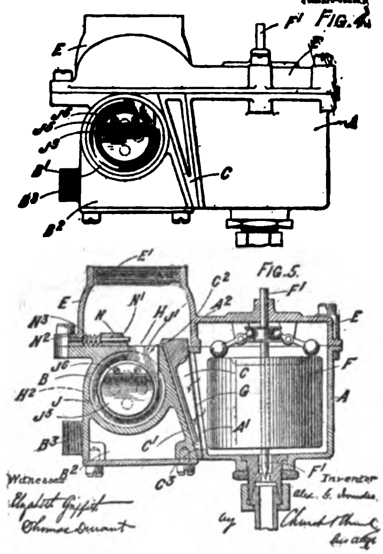
1,011,960. A. G. IONIDES. CARBURETER. Patented Dec. 19, 1911.



A. G. [illegible]
CARBURETER.
APPLICATION FILED JAN. [illegible]
1,011,960. Patented Dec. 19, 1911.
[illegible]



A. G. [illegible]
CARBURETER.
APPLICATION FILED JAN. [illegible]
1,011,960. Patented Dec. 19, 1911.
[illegible]



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CARBURETER.
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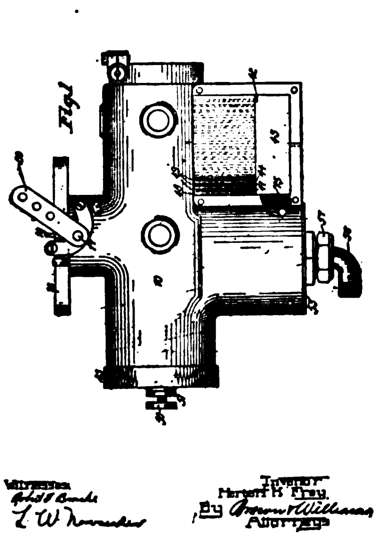
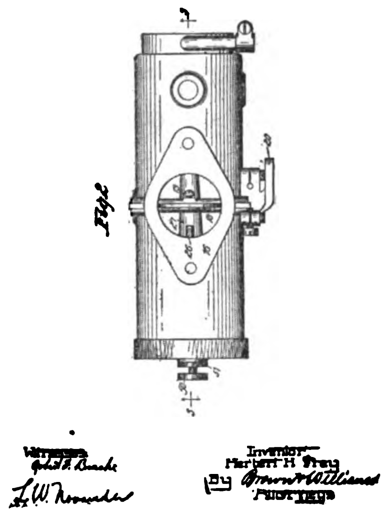
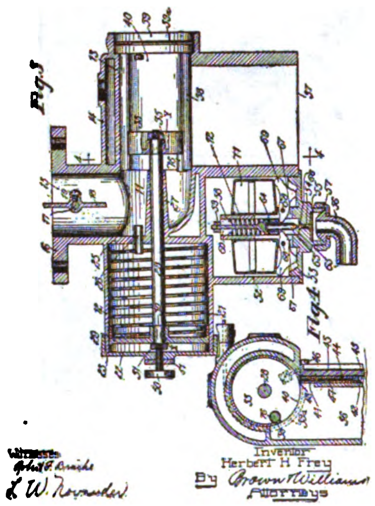
[illegible]



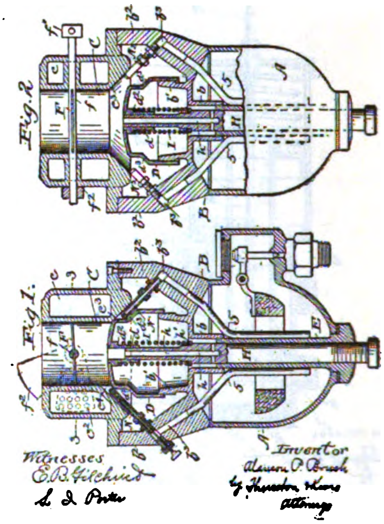
H. H. FREY.
CARBURETER.
APPLICATION FILED NOV. 11, [illegible]
1,119,076. Patented Dec. 1, 1914.
[illegible]



H. H. FREY.
CARBURETER.
1,119,078. Patented Dec. 1, 1914.



A. P. BRUSH.
CARBURETER.
1,180,474.



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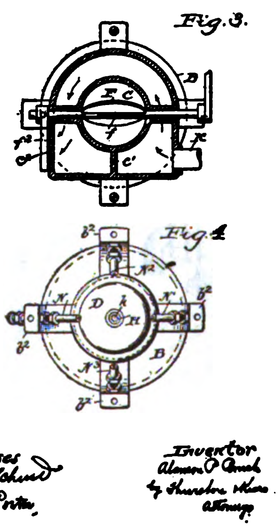
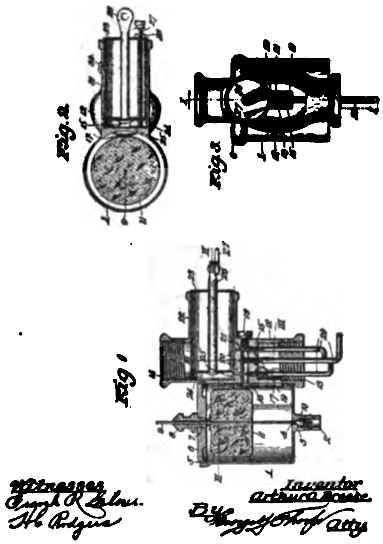
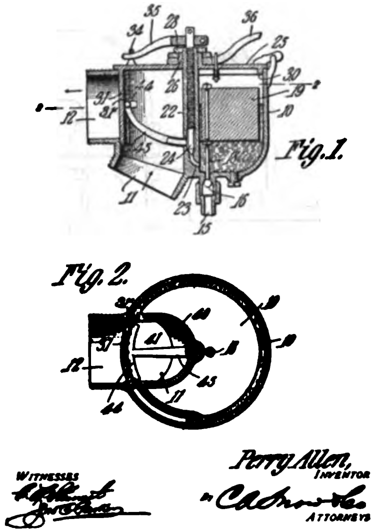
CARBURETER.
1,180,474.



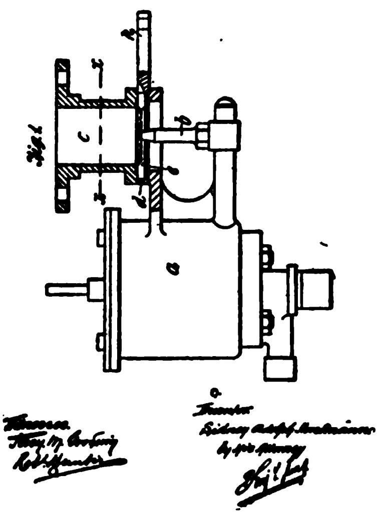
A. C. BROOKE.
CARBURETER.



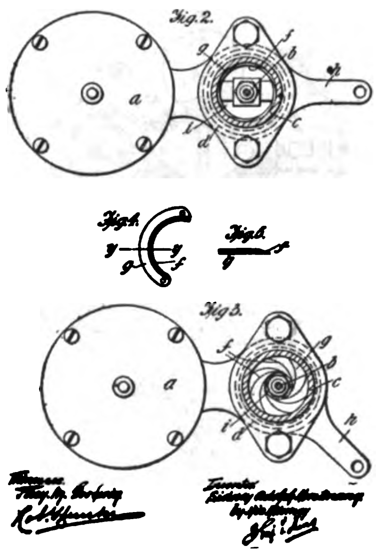
No. 661,279. PATENTED MAR. 16, 1909.
P. ALLEN.
CARBURETER FOR INTERNAL COMBUSTION ENGINES.



PATENTED MAR. 16, 1909
S. A. HORSTMANN.
CARBURETER FOR INTERNAL COMBUSTION ENGINES.



PATENTED MAR. 16, 1909
S. A. HORSTMANN.
CARBURETER FOR INTERNAL COMBUSTION ENGINES.



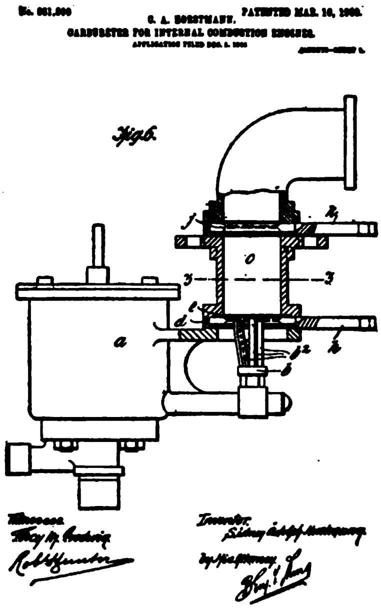


Fig. 6.

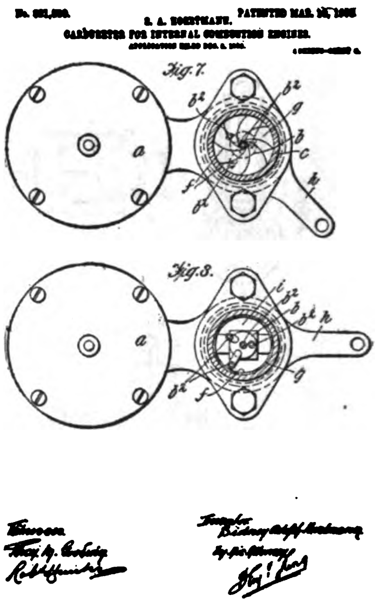
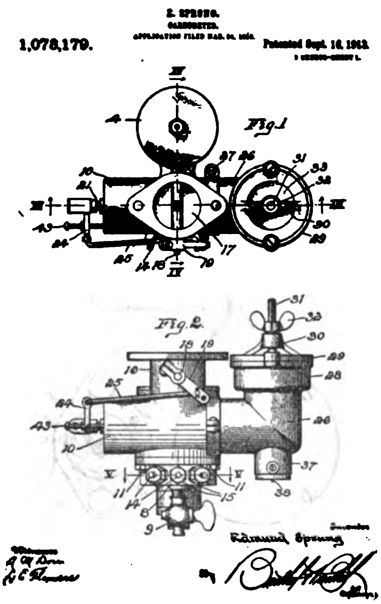
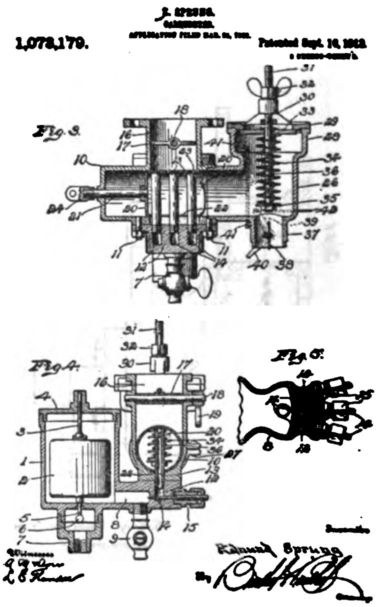


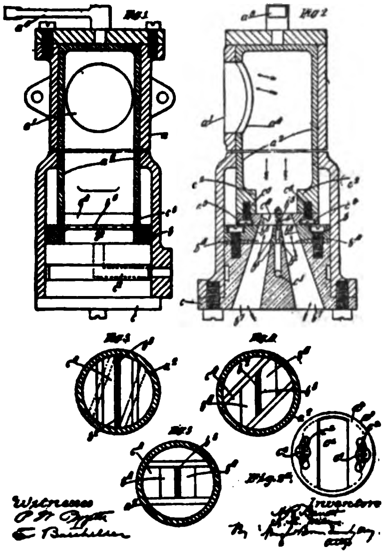
Fig. 7.
Fig. 8.


E. SPRUNG.
CARBURETER.
1,073,179.
Fig. 1
Fig. 2.
Edmund Sprung


E. SPRUNG.
1,073,179.
Fig. 3.
Fig. 4.
Fig. 5.
Edmund Sprung

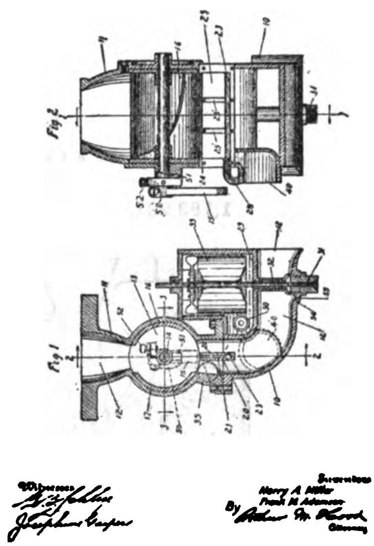
E. D. BARRETT & E. McG. WILSON.
CARBURETER.
APPLICATION FILED OCT. 6, 1910.

1,069,594. Patented Mar. 10, 1914.



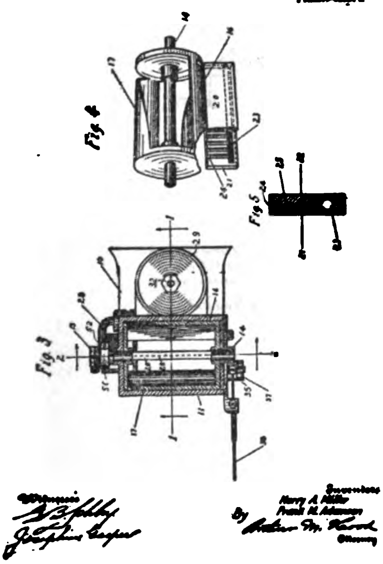
R. A. MILLER & F. M. ADAMSON.
CARBURETER.
APPLICATION FILED SEPT. 16, 1910.

1,094,674. Patented Apr. 28, 1914.
2 SHEETS—SHEET 1.



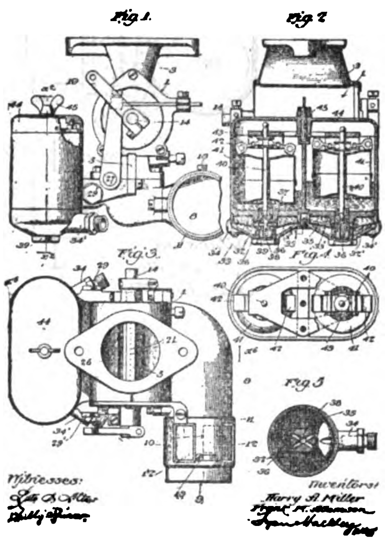
R. A. MILLER & F. M. ADAMSON.
CARBURETER.
APPLICATION FILED SEPT. 16, 1910.

1,094,674. Patented Apr. 28, 1914.
2 SHEETS—SHEET 2.



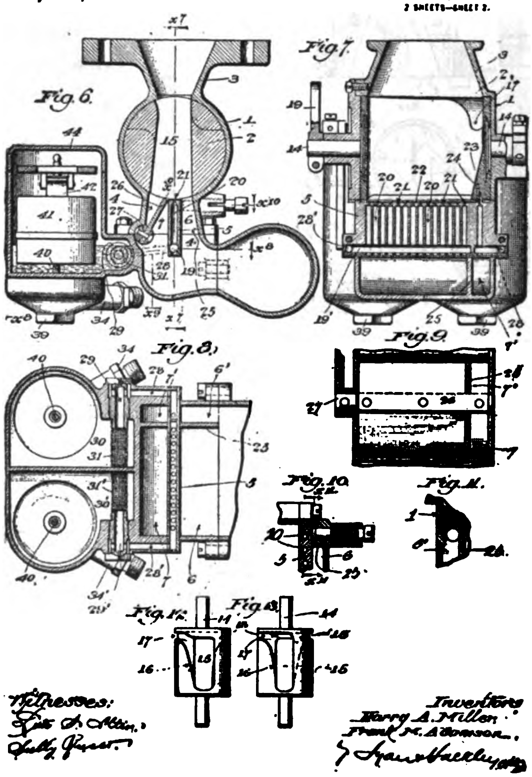
H. A. MILLER & F. M. ADAMSON.
DOUBLE FUEL CARBURETER.
APPLICATION FILED MAY 4, 1914.

1,183,291. Patented May 16, 1916.
2 SHEETS—SHEET 1.

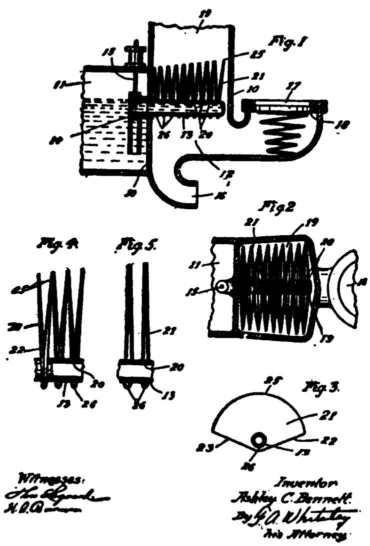


H. A. MILLER & F. M. ADAMSON
DOUBLE FUEL CARBURETER.
APPLICATION FILED MAY 4, 1914

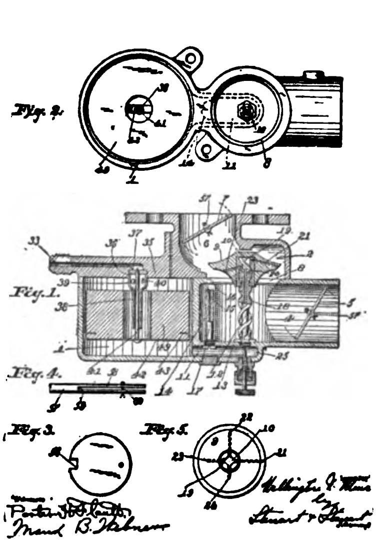
1,183,221. Patented May 16, 1916.
2 SHEETS—SHEET 2.

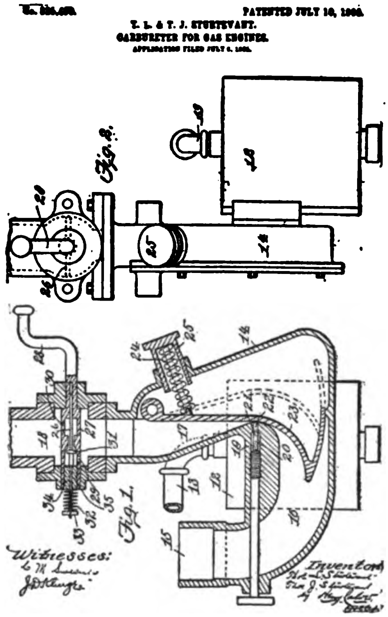


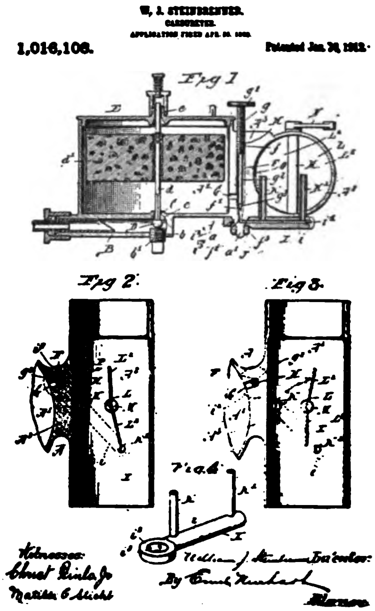
1,130,700.

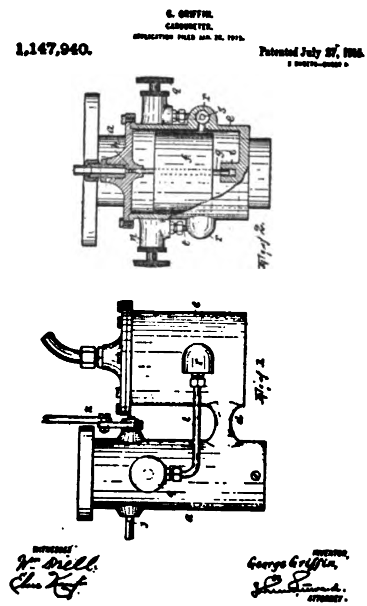


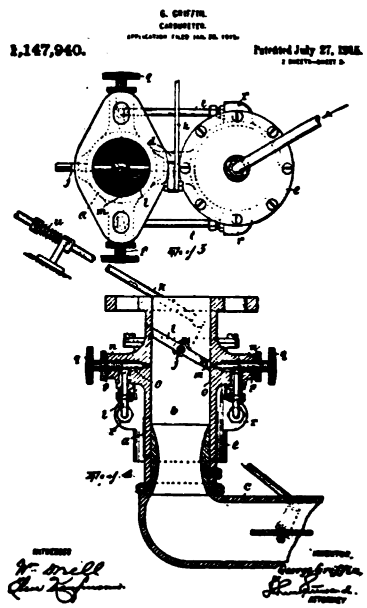
1,147,887.




PATENTED JULY 10, 1906.
T. L. & T. J. STURTEVANT.
CARBURETER FOR GAS ENGINES.

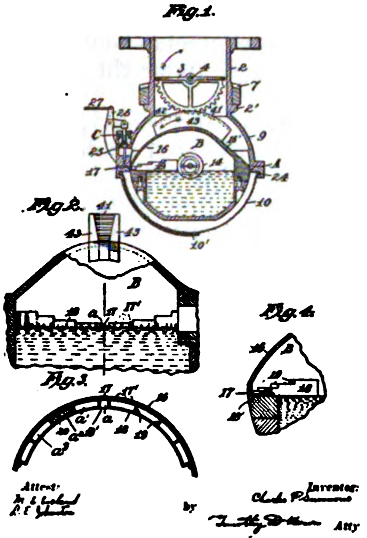

W. J. STEINBRENNER.
CARBURETER.
1,016,108.


G. GRIFFIN.
CARBURETER.
1,147,940.


G. GRIFFIN.
CARBURETER.
1,147,940.

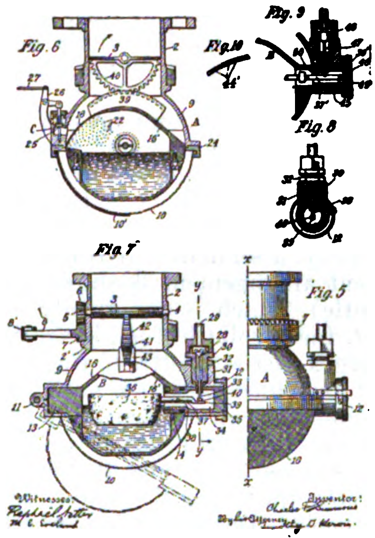
C. F. SIMMONS.
CARBURETER.

989,807. Patented Apr. 11, 1911.



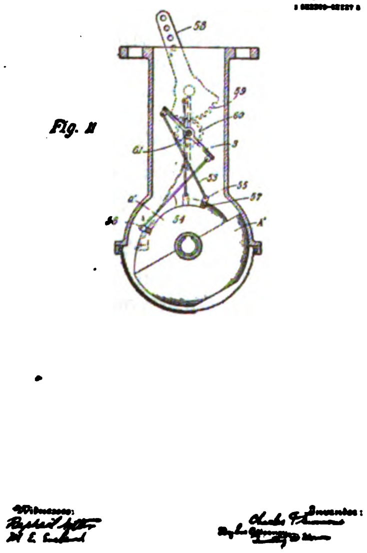
C. F. SIMMONS.
CARBURETER.

989,807. Patented Apr. 11, 1911.



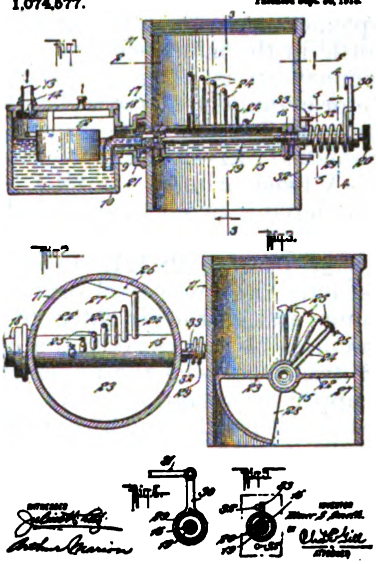
C. F. SIMMONS.
CARBURETER.

989,807. Patented Apr. 11, 1911.



SMITH.
CARBURETER.

1,074,577. Patented Sept. 30, 1913.



Class 10—Carburetors, proportioning flow, aspirating, multiple fixed-fuel inlets and multiple variable-air inlets, valved for regulation.—The only difference between this and the other class of multiple fixed-fuel inlets with multiple variable-air inlets is the sort of air inlets, which in the former class were fixed, whereas in the present class they have at least one air-regulating valve. Besides those cases that clearly fall under one or more of the subclass definitions there are some that do not, and these are grouped under the general class.

In the first case, on page 343 (979,700, Dec. 27, 1910, Proehl), a semicircular ring of fuel inlets is arranged to be uncovered successively by a rotating cylindrical sleeve, and thus subjected to a flow-inducing vacuum of the air velocity, which is prevented from increasing as much as it otherwise would by a secondary automatic valve. Incidentally, a semicircular throttle moves with the sleeve. Quite a different arrangement is shown on page 343 (1,099,547, June 9, 1914, Gentle), which is practically a pair of carburetors in series. The first, for a volatile fuel, has a fixed air and fuel air inlet, and it discharges past a throttle to the second supplied with a less volatile fuel and provided with an automatic air valve, having the fuel inlet around its seat. When the engine becomes warm enough a thermostat closes the throttle of the first carburetor and at the same time opens a pure-air inlet to the second. Another case of double carburetor operating alternately instead of in series is that on page 344 (1,163,393, Dec. 7, 1915, Corbett). Here the main carburetor has a fixed primary and automatic secondary air inlet with single fixed fuel inlet, but there is another with automatic air inlet lifting a fuel valve in front of it somewhat similar to those of class 1. A cam permitting the opening of either the main automatic secondary or the supplementary automatic air and fuel valves is linked to a special throttle in the main primary air, so it is closed at the same time its secondary air is. This is a sort of high and low speed double-carburetor arrangement, controlled by a separate hand-operated linkage, independent of either the vacuum or the main throttle.

Subclass 10.1—Main fuel inlet with supplementary high-speed jet.—A fixed primary air inlet of tapered form is fitted with a fuel nozzle having two orifices at different levels and a side entrance automatic secondary air valve is provided for each in the form shown on page 345. (928,121, July 13, 1909, Goldberg.) At low-flow rates only the lower fuel orifice is in action, by reason of the low vacuum, and all the air enters by the fixed inlet. Increased flow and vacuum cause successively the opening of the lower secondary air, fuel discharge from the upper fuel orifice, and then the opening of the upper secondary air valve. Two fixed jets arranged on opposite sides of a throttle which controls both the relative and the absolute flow through the two chambers is illustrated on pages 345 and 346. (958,476, May 17, 1910, Cook.) The low-speed jet, so called because it is in action when the other is not on a nearly closed throttle, has an automatic air-inlet valve, while the high-speed jet is arranged in a fixed primary air passage with an automatic secondary air inlet. At all throttle positions except the nearly closed one both jets are in action. A combination, in which the high-speed jet is brought into action by the vacuum lift on the automatic secondary air valve of the low-speed jet, is shown on page 346. (993,770, May 30, 1911, Fritz.)

Another case of bringing in the high-speed jet by the throttle is shown on page 346. (1,046,434, Dec. 10, 1912, Bollee.) Here an accelerating cup is added to the low-speed jet, which is fixed in a fixed-air inlet, the cup emptying as the throttle is opened and before the high-speed jet comes in. The high-speed jet has its own separate tube with fixed primary and ball type of automatic secondary air valve. An unusual form of throttle controlling the action of the high-speed jet is shown on pages 346 and 347. (1,078,349, Nov. 11, 1913, Hawxhurst & Nicolai.) This throttle stem carries first a small poppet valve which opens wide the outlet from the low-speed jet in its fixed air passage, then in succession a series of three concentric poppets are opened in succession, admitting to the main mixing chamber the delivery from the high-speed jet gradually, and at the same time increasing the spring tension of the automatic secondary air valve of the high-speed chamber.

Another case of two jets at different levels in one chamber is shown on page 347 (1,099,293, June 9, 1914, Goldberg and Tillotson), the high-level high-speed jet being brought into action by the opening of the secondary automatic air valve indirectly as it closes an air hole from the atmosphere to the high-speed jet passage which permits the vacuum to build up and the jet to work, as it could not so long as this air hole was open. The same result could, of course, be accomplished by a direct mechanical connection from the secondary air valve to a fuel valve at the high-speed jet or by the vacuum alone. Succession by the velocity of the secondary air alone is shown on page 347. (1,120,763, Dec. 15, 1914, Thomas.) The high-speed jet is here located in the air throat in front of the automatic secondary air valve.

Subclass 10.2—Main fuel inlet with supplementary idling jet.—The principal difference between this and the previous subclass is one of succession versus alternation. In the previous case the low-speed jet continued to work after the high-speed jet came into action, here a low-speed or idling jet gives way to, or is replaced by the high-speed jet, no matter what the mechanism of alternation may be. In the case on page 348 (1,055,352, Mar. 11, 1913, Pembroke), a small fuel tube is carried from the float chamber to a point above the throttle and is in action only when the vacuum there is great enough to lift the fuel, which it can not do at open throttle, because the main carburetor proper is of the automatic air-valve class. The same result is attained on page 348 (1,104,560, July 21, 1914, Shoobridge & Gunstone), by drilling the walls and leading through these holes both fuel air to the stem of the throttle, rotation of the stem acting as a valve with reference to the holes in it and the wall. A different construction again is shown on pages 348 and 349. (1,166,308, Dec. 28, 1915, Arquembourg.)

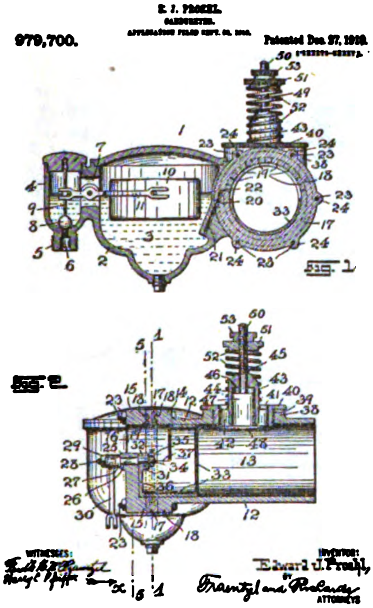
Subclass 10.3—Multiple carburetor, progressive, by throttle, with individual automatic air inlet regulating valves.—This is the subclass of multicarburetors with automatic air valves with throttle control of succession, and as arranged on page 350 (871,741, Nov. 19, 1907, Sturtevant & Sturtevant), there are two units connected to a three-ported throttle by means of which either the large or the small one, or both, may be brought into action. Five carburetors, each with fixed fuel inlet and swing type automatic air inlets, are brought in successively by the rotation of a cylindrical sleeve throttle

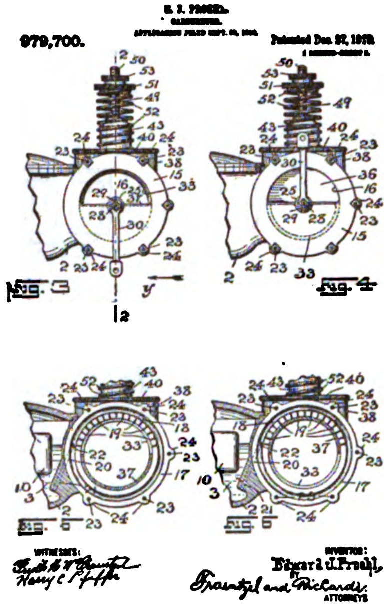
on pages 350 and 351. (881,516, Mar. 10, 1908, Krebs.) Rotation of a large barrel throttle brings in four units on pages 351 and 352 (891,219, June 16, 1908, Menns), but here there is added at the end of the throttle a common automatic secondary air valve. Three units arranged radially in a taper air passage with three radial partitions are controlled by a rotating throttle disk; each one is supplied with primary and secondary air, both vacuum controlled in the form, page 352. (1,001,950, Aug. 29, 1911, Hart.) A pair of plain secondary air-valve carburetors are arranged side by side, using one float chamber and each with its own throttle, on page 353 (1,152,031, Aug. 31, 1915, Lobdell), but the throttles are so linked together as to bring about the action of each in succession.

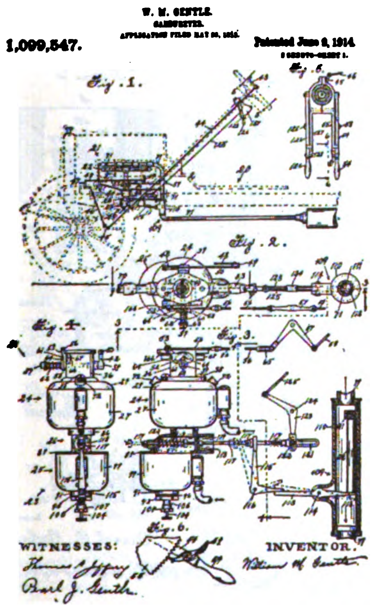
Subclass 10.4—Multiple carburetor, progressive by vacuum, with individual automatic air inlet regulating valves.—Just as with single carburetors vacuum control of any regulating valve in a carburetor intended for general service, including variable speed engines, is more logical than throttle control, so here in the control of succession of multiple carburetors the same should be true. This being the case, the present subclass is of greater interest than the preceding one though any good features of one could be worked into the other by a designer. If an automatic air-valve carburetor worked as a self-compensating device then there would seem to be no need for multiple carburetors of this class and there are not many. One of these is shown on page 354 (1,040,414, Oct. 8, 1912, Rettig), where three automatic air-valve carburetors are arranged around one float chamber, each air valve not only regulating the fuel flow vacuum of its own chamber but also opening the discharge from it. The vacuum at the outlet thus becomes the main lifting factor in the air-valve movement instead of the air flow between it and the fuel nozzle. Another of this class is shown on page 354 (1,108,245, Aug. 25, 1914, Schebler) with one main fuel jet in a fixed air passage and automatic secondary air, but having in addition five high level high-speed jets brought in when the vacuum lifts the several corresponding air valves.

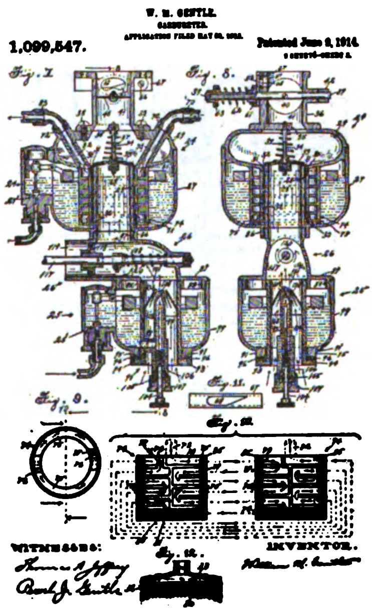
Subclass 10.5—Standpipes.—On page 355 (961,481, June 14, 1910, Carter) is shown a fuel standpipe in a fixed primary air inlet to which is also attached a secondary air valve, thus providing a double compensation. An increase in the size of the primary air inlet and a tapered form for it surrounding the standpipe is shown on page 355 (1,010,116, Nov. 28, 1911, Carter), to which is also added a low speed or idling lifting tube and a lowest level separate jet in action all the time. The secondary automatic swing-type air valve is retained. Another form of standpipe with one fixed and one automatic air inlet is shown on page 356 (1,133,527, Mar. 30, 1915, Bennett), which has some other interesting features to adapt it to heavy fuels. One is a water inlet beyond the fuel, and the other is an exhaust-heated jacket for the float-chamber bowl and the interior of the liquid standpipe.

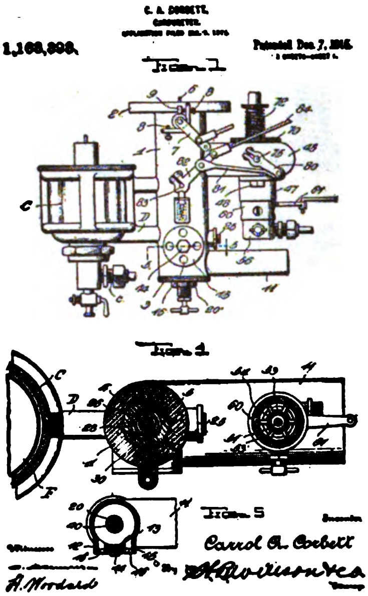
Subclass 10.16—Mixed flow.—Two fuel inlets arranged on opposite sides of a cylindrical air passage fitted with a single air valve are provided with mixed flow compensation on page 357. (1,168,513, Jan. 18, 1916, Kingston.) Each fuel inlet has the accelerating cup enlargement of its mixed flow air passage, previously noted in several other cases. The air or throttle valve is thick and more or less

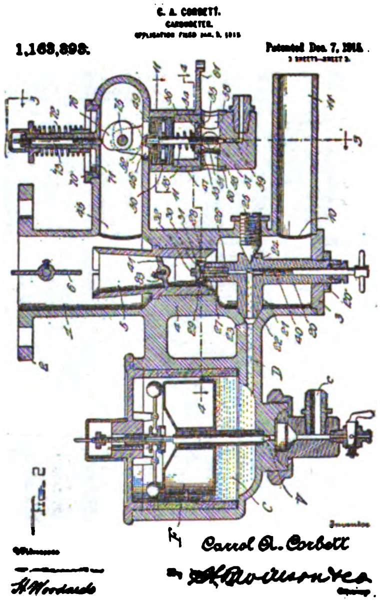

E. J. PROEHL.
979,700.
WITNESSES:
INVENTOR:
Edward J. Proehl,
ATTORNEYS

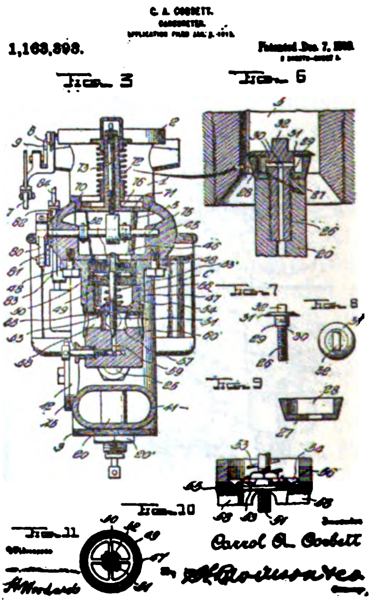

979,700.
WITNESSES:
INVENTOR:
Edward J. Proehl,
ATTORNEYS

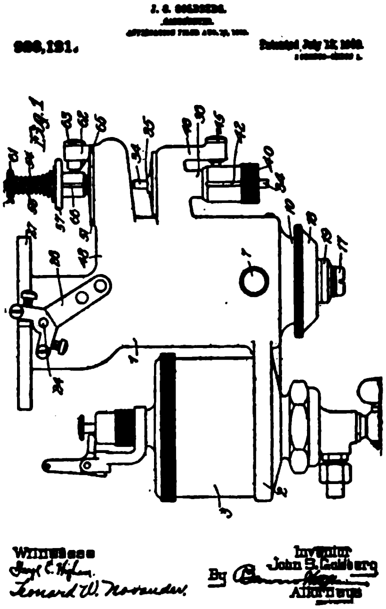

W. M. GENTLE.
1,099,547.
WITNESSES:
INVENTOR.

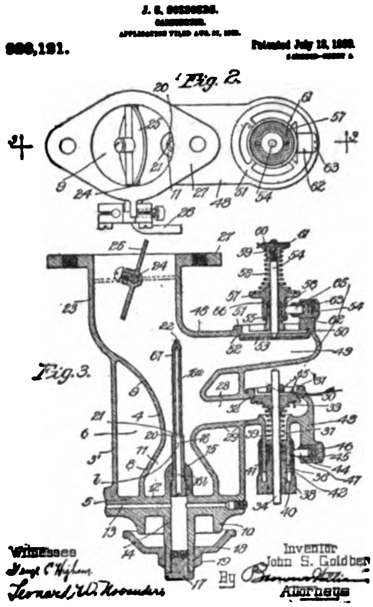

W. M. GENTLE.
1,099,547.
WITNESSES:
INVENTOR.

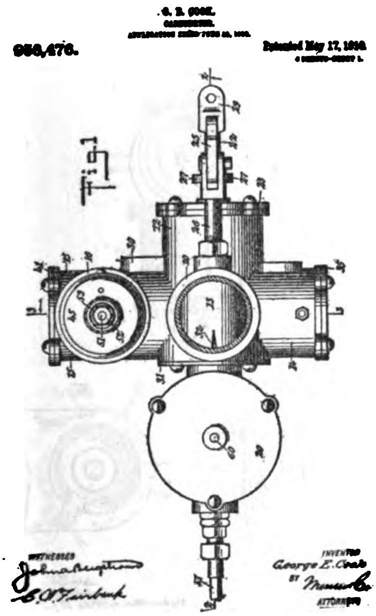

C. A. CORBETT.
CARBURETER.
1,163,898.
Patented Dec. 7, 1915.
Fig. 1
Fig. 4
Fig. 5
Carrol A. Corbett

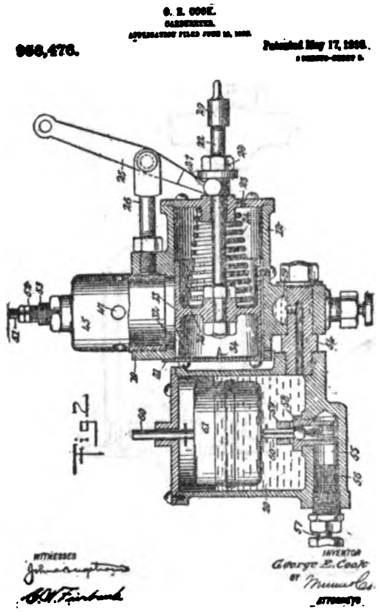

C. A. CORBETT.
CARBURETER.
1,163,898.
Patented Dec. 7, 1915.
Fig. 2
Carrol A. Corbett


C. A. CORBETT.
CARBURETER.
1,163,898.
Patented Dec. 7, 1915.
Fig. 3
Fig. 6
Fig. 7
Fig. 8
Fig. 9
Fig. 10
Fig. 11
Carrol A. Corbett


928,131.
Patented July 13, 1909.
Fig. 1
Witnesses
Inventor
John S. Goldberg
By
Attorneys

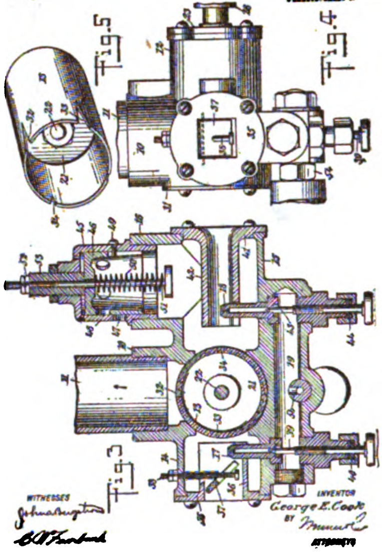

928,131.
Patented July 13, 1909.
Fig. 2
Fig. 3
Witnesses
Inventor
John S. Goldberg
By
Attorneys


958,476.
Patented May 17, 1910.
Fig. 1
Witnesses
Inventor
George E. Cook
By Munn & Co.
Attorneys


958,476.
Patented May 17, 1910.
Fig. 2
Witnesses
Inventor
George E. Cook
By Munn & Co.
Attorneys

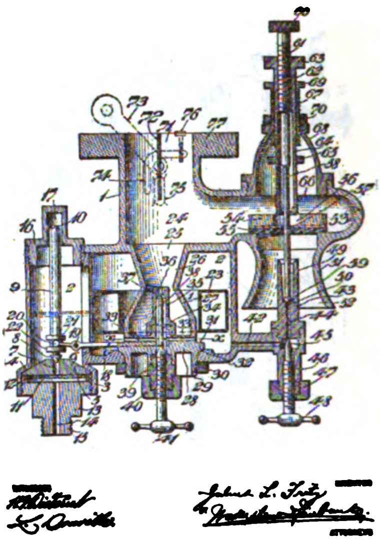
G. E. COOK.
CARBURETER.

958,476. Patented May 17, 1910.



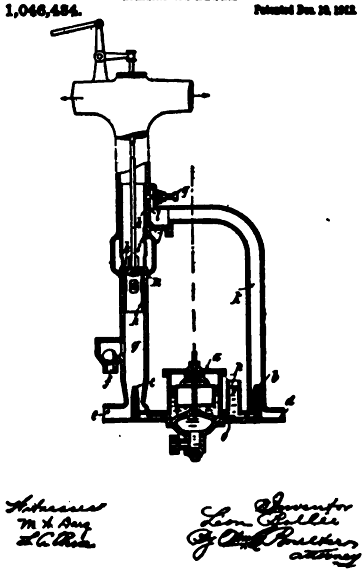
J. L. FRITZ.
CARBURETER.

998,770. Patented May 30, 1911.



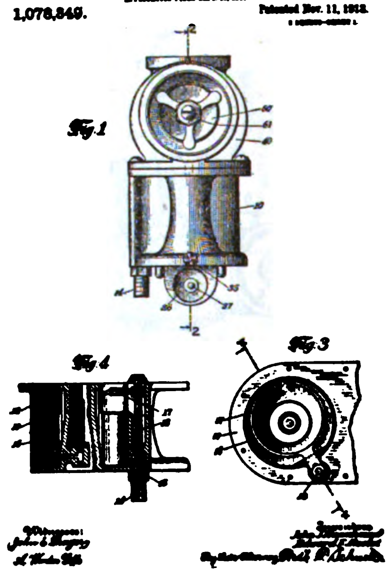
L. BOLLÉE.
CARBURETER.

1,046,484. Patented Dec. 10, 1912.



J. J. HAWKHURST & R. F. NICOLAI.
CARBURETING DEVICE.

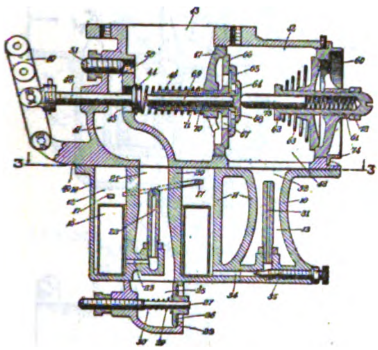
1,078,849. Patented Nov. 11, 1913.



J. S. HAWKHURST & E. F. NICOLAI.
CARBURETING DEVICE.
APPLICATION FILED SEPT. [illegible], 1910.

1,078,349. Patented Nov. 11, 1913.
[illegible] SHEETS-SHEET 2.

Fig. 2

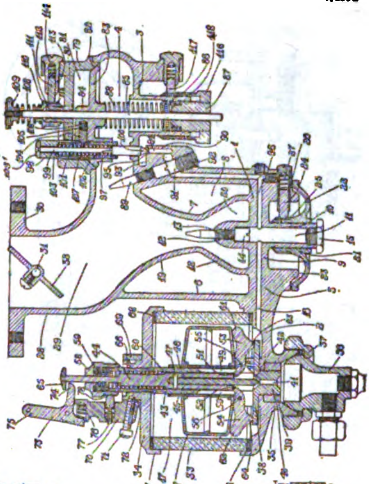


Witnesses:

Inventors
By their Attorney

J. S. GOLDBERG & H. C. TILLOTSON.
CARBURETER.
APPLICATION FILED JAN. 26, 1909. RENEWED APR. 18, 1914.

1,099,998. Patented June 9, 1914.



Witnesses
George E. Higham
Frank J. [illegible]

Inventors
John S. Goldberg
Harry C. Tillotson
By Brown & Williams
Attorneys

H. T. THOMAS.
CARBURETER.
APPLICATION FILED OCT. [illegible], 1909.

1,120,768. Patented Dec. 15, 1914.

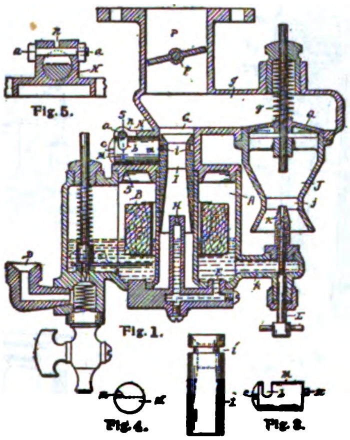


Fig. 5.

Fig. 1.

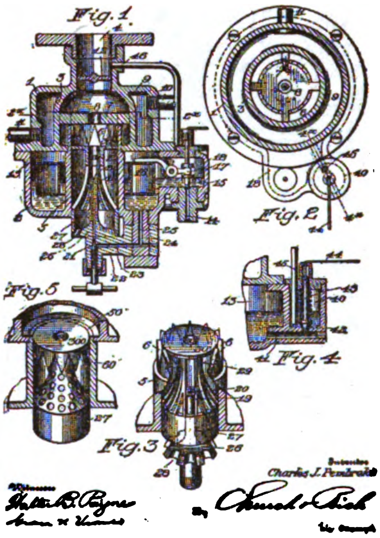
Fig. 4.

Fig. 3.

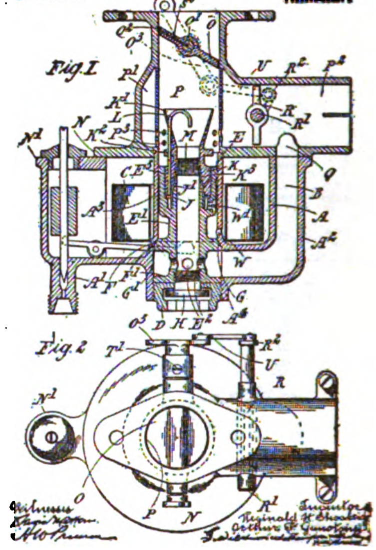
Fig. 2.

Horace T. Thomas
Parker & Smith

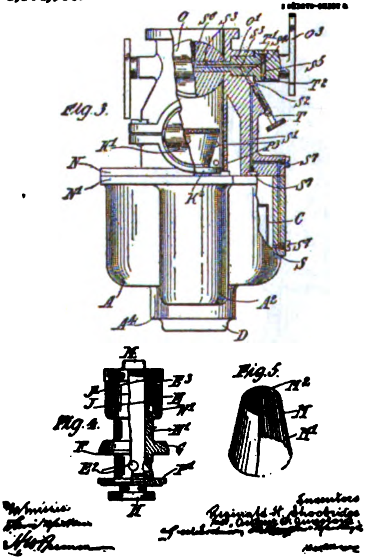
1,055,352. Patented Mar. 11, 1913.



1,104,560. Patented July 21, 1914.

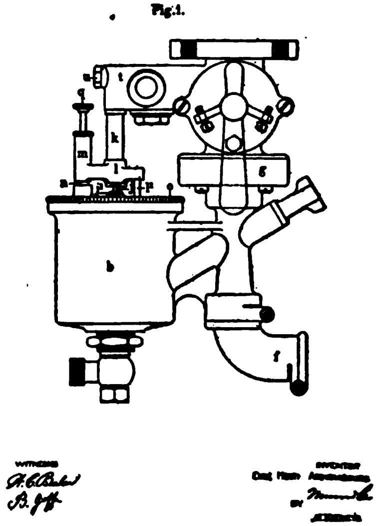


1,104,560. Patented July 21, 1914.



1,166,806. Patented

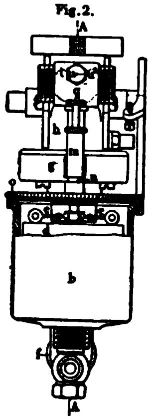
Fig:1.



E. H. ARQUEMBOURG.
CARBURETTER.
APPLICATION FILED JAN. 17, 1913.

1,166,308. Patented Dec. 28, 1915.
3 SHEETS—SHEET 2.

Fig. 2.



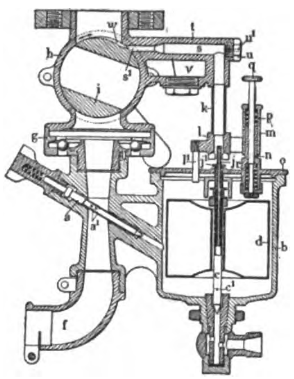
WITNESSES
H. B. Baker
B. Jaffe

INVENTOR
EMILE HENRI ARQUEMBOURG
BY Munn & Co.
ATTORNEYS.

E. H. ARQUEMBOURG.
CARBURETTER.
APPLICATION FILED JAN. 17, 1913.

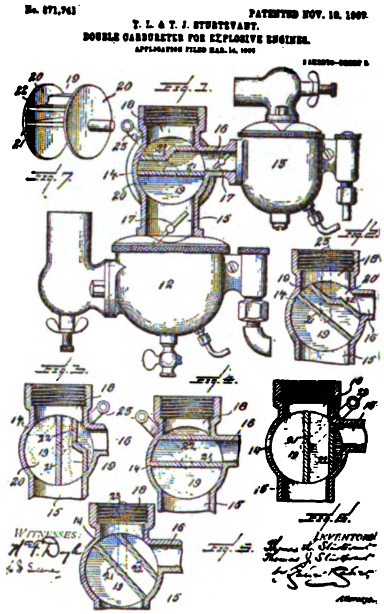
1,166,308. Patented Dec. 28, 1915.
3 SHEETS—SHEET 3.

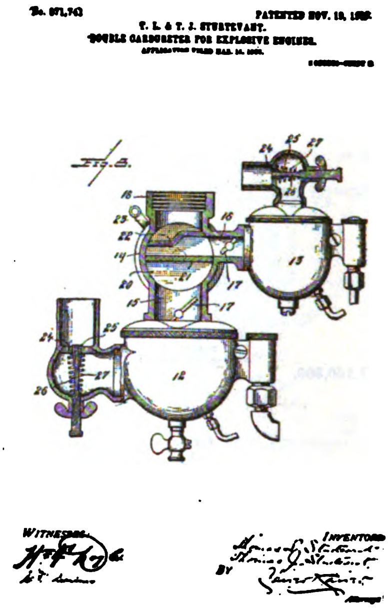
Fig. 3.

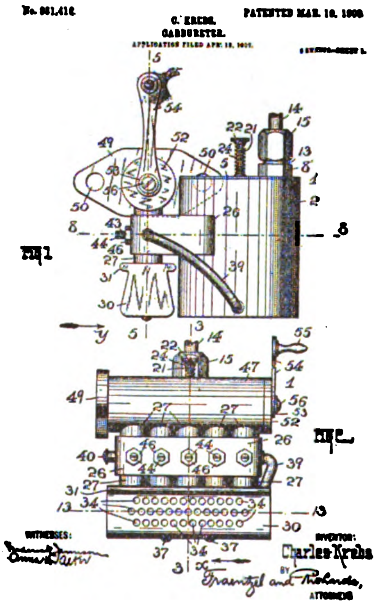


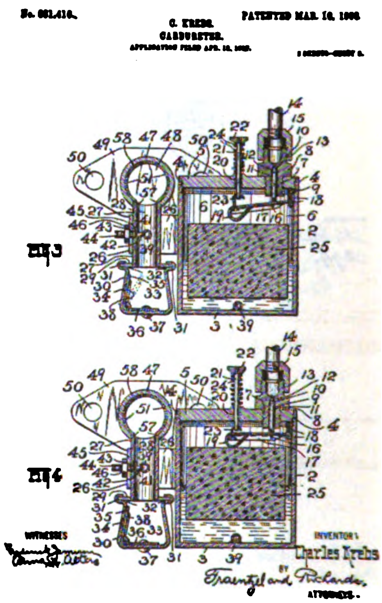
WITNESSES
H. B. Baker
B. Jaffe

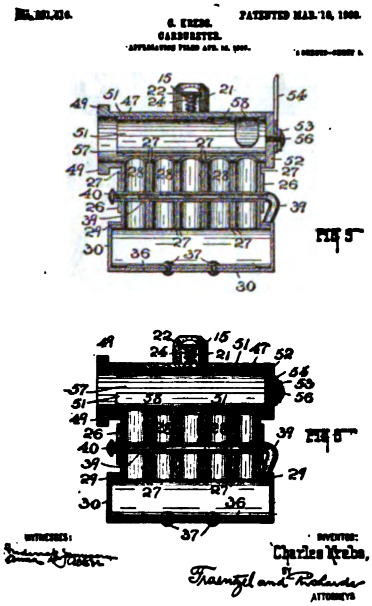
INVENTOR
EMILE HENRI ARQUEMBOURG
BY Munn & Co.
ATTORNEYS.

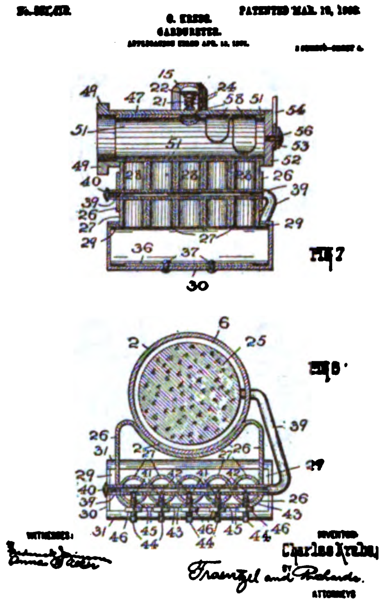

No. 871,741.
PATENTED NOV. 19, 1907.
T. L. & T. J. STURTEVANT.
DOUBLE CARBURETER FOR EXPLOSIVE ENGINES.
WITNESSES:
INVENTORS
Attorneys.

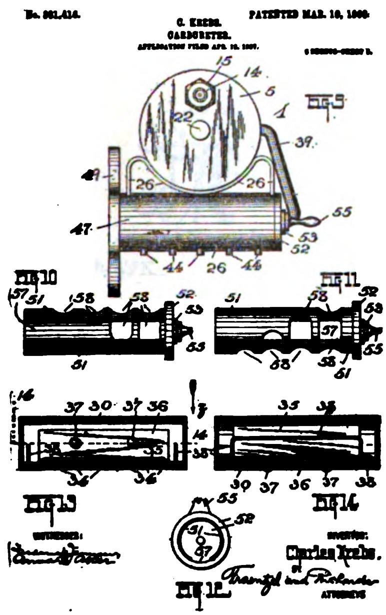

No. 871,741.
PATENTED NOV. 19, 1907.
T. L. & T. J. STURTEVANT.
DOUBLE CARBURETER FOR EXPLOSIVE ENGINES.
WITNESSES:
INVENTORS
BY
Attorneys.

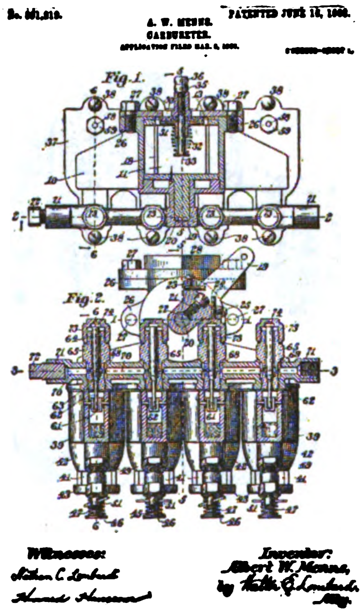

No. 881,416.
PATENTED MAR. 10, 1908.
C. KREBS.
CARBURETER.
FIG. 1
FIG. 2
WITNESSES:
INVENTOR:
Charles Krebs
BY
Fraentzel and Richards,
ATTORNEYS.


No. 881,416.
PATENTED MAR. 10, 1908.
C. KREBS.
CARBURETER.
FIG. 3
FIG. 4
WITNESSES:
INVENTOR:
Charles Krebs
BY
Fraentzel and Richards,
ATTORNEYS.

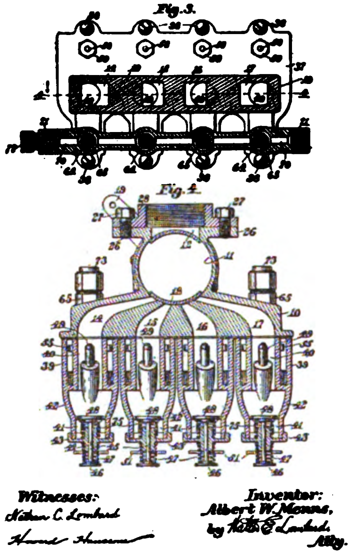

C. KREBS.
CARBURETER.
FIG 5
WITNESSES:
INVENTOR:
Charles Krebs,
ATTORNEYS


C. KREBS.
CARBURETER.
FIG 7
FIG 8
WITNESSES:
INVENTOR:
Charles Krebs,
ATTORNEYS

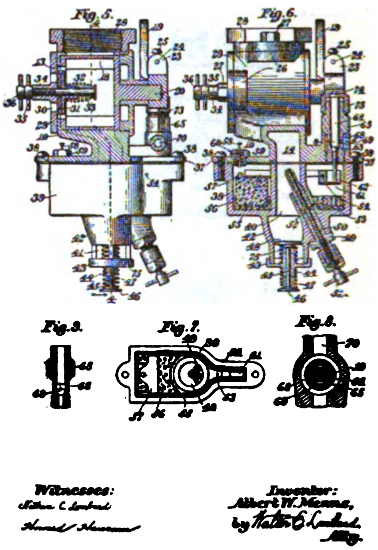

C. KREBS.
CARBURETER.
FIG 9
FIG 10
FIG 11
FIG 13
FIG 14
FIG 12
WITNESSES:
INVENTOR:
Charles Krebs,
ATTORNEYS


A. W. MENNS.
CARBURETER.
Fig. 1.
Fig. 2.
Witnesses:
Inventor:
Albert W. Menns,
by Walter E. Lombard,
Atty.

No. 891,819. A. W. MENNS. CARBURETER. APPLICATION FILED MAR. 6, 1908. PATENTED JUNE 16, 1908. 2 SHEETS—SHEET 2.

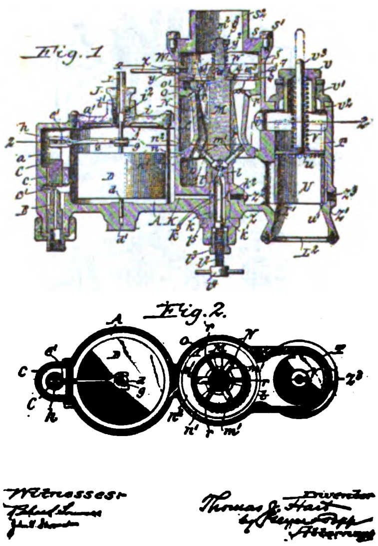


No. 891,819. A. W. MENNS. CARBURETER. APPLICATION FILED MAR. 6, 1908. PATENTED JUNE 16, 1908. 2 SHEETS—SHEET 1.



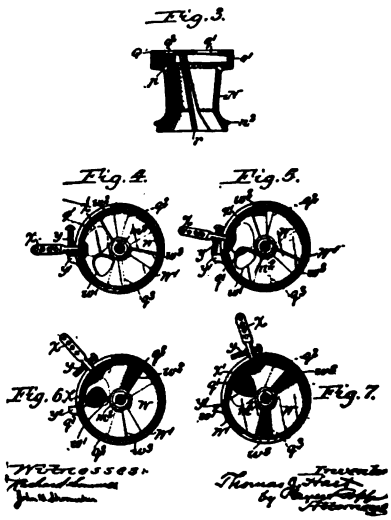
T. J. HART. CARBURETER. APPLICATION FILED NOV. 26, 1909.

1,001,950. Patented Aug. 29, 1911. 2 SHEETS—SHEET 1.



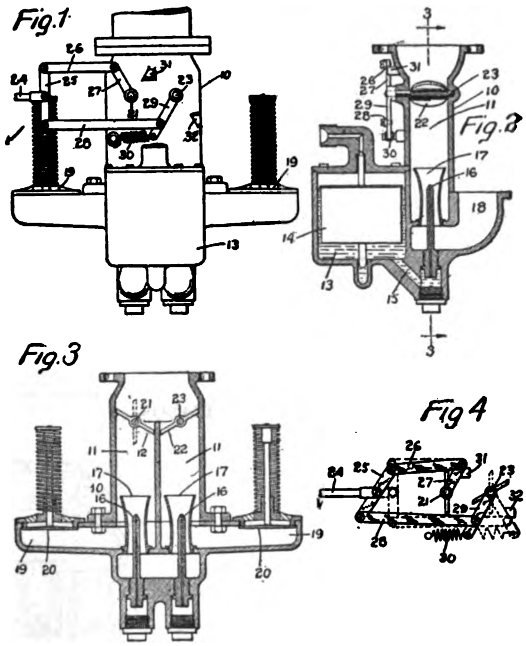
T. J. HART. CARBURETER. APPLICATION FILED NOV. 26, 1909.

1,001,950. Patented Aug. 29, 1911. 2 SHEETS—SHEET 2.



F. S. LOBDELL.
CARBURETER.
APPLICATION FILED MAR. 9, 1912.

1,152,031. Patented Aug. 31, 1915.

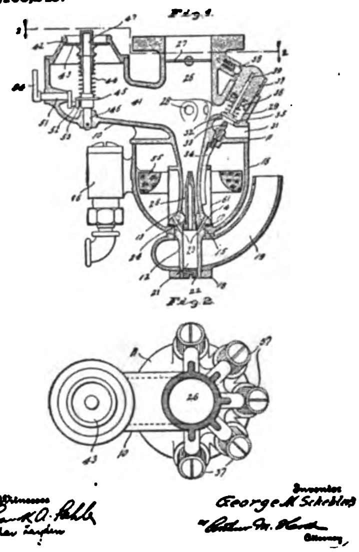


WITNESSES:
E. M. Culver

INVENTOR
Frank S. Lobdell
BY
ATTORNEY

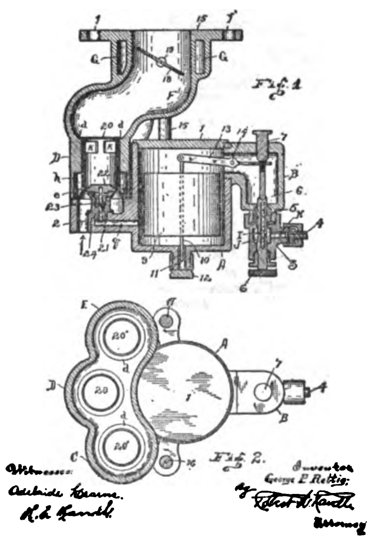
G. M. SCHEBLER.
CARBURETER.
APPLICATION FILED MAR. 21, 1913.

1,108,945. Patented Aug. 25, 1914.



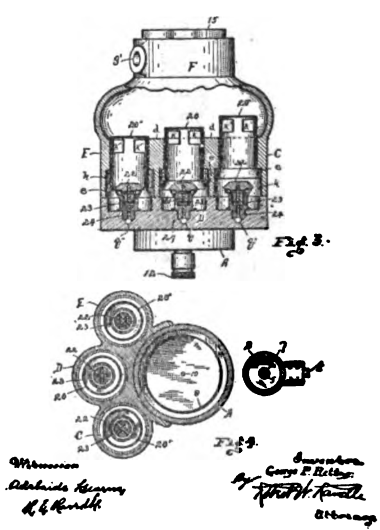
G. P. RETTIG.
CARBURETER.
APPLICATION FILED SEPT. 7, 1909.

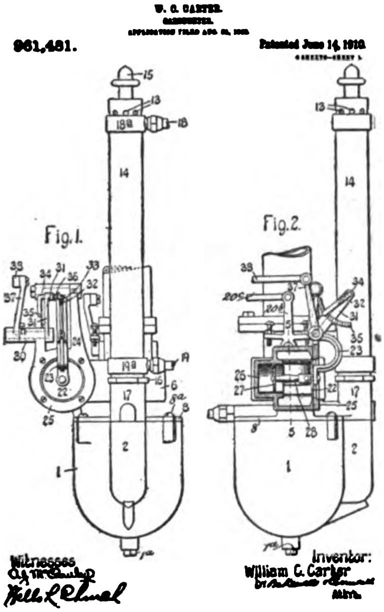
1,040,414. Patented Oct. 8, 1912.
2 SHEETS—SHEET 1.

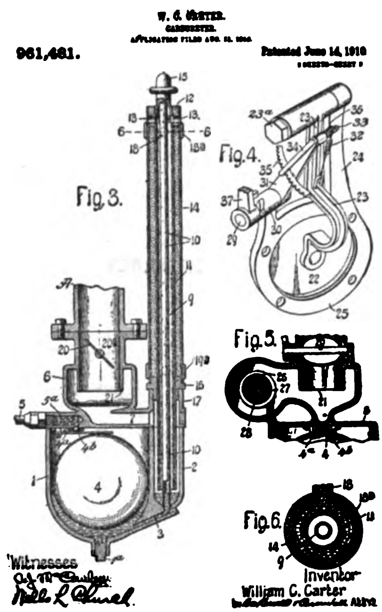


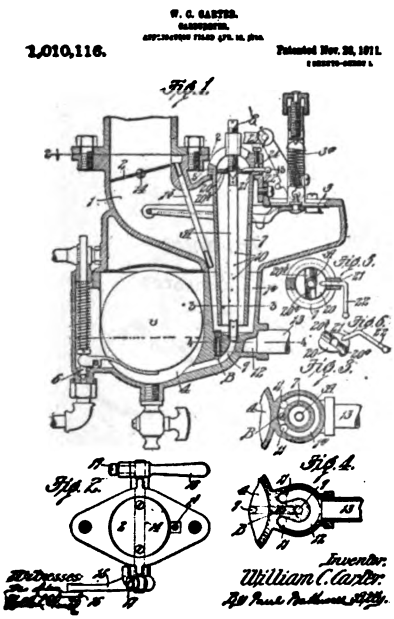
G. P. RETTIG.
CARBURETER.
APPLICATION FILED SEPT. 7, 1909.

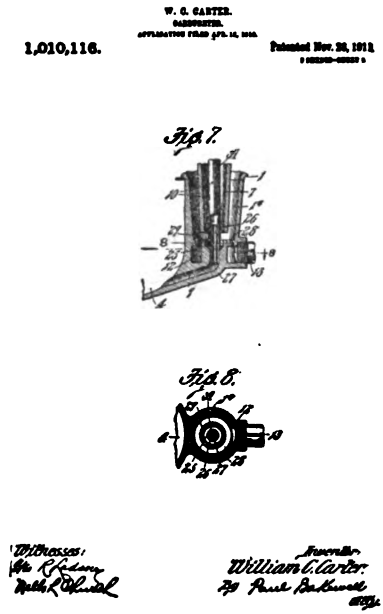
1,040,414. Patented Oct. 8, 1912.
2 SHEETS—SHEET 2.




W. C. CARTER.
CARBURETER.
961,481.
Patented June 14, 1910.
Fig. 1.
Fig. 2.
Witnesses
Inventor:
William C. Carter


W. C. CARTER.
CARBURETER.
961,481.
Patented June 14, 1910.
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 6.
Witnesses
Inventor
William C. Carter


W. C. CARTER.
CARBURETER.
1,010,116.
Patented Nov. 28, 1911.
Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 6.
Witnesses
Inventor:
William C. Carter.


W. C. CARTER.
CARBURETER.
1,010,116.
Patented Nov. 28, 1911.
Fig. 7.
Fig. 8.
Witnesses:
Inventor:
William C. Carter.

A. C. BENNETT.
CARBURETER.
APPLICATION FILED MAR. 12, 1913.

1,133,597. Patented Mar. 30, 1915.

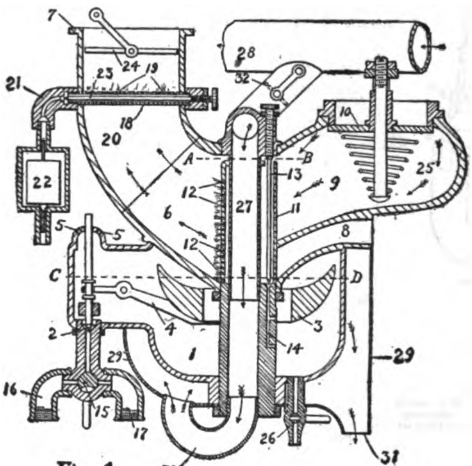


Fig. 1

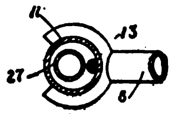


Fig. 2

Witnesses

Wm. Ross
H. A. Bowman.

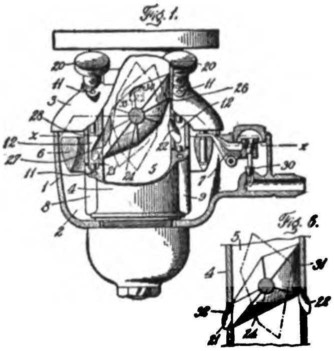
Inventor

Ashley C. Bennett.
By F. A. Whiteley
His Attorney

G. KINGSTON.
CARBURETER.
APPLICATION FILED JAN. 5, 1912.

1,168,513. Patented Jan. 18, 1916.
3 SHEETS—SHEET 1.

Fig. 1. Fig. 6.



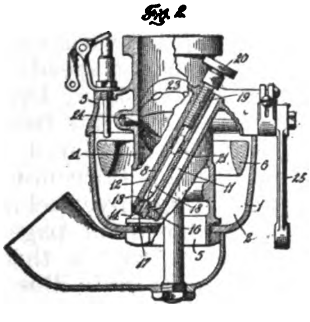
Witnesses
Chas. W. Stauffiger.
Jas. M. Davis

Inventor
George Kingston,
By [signature]
Attorney

G. KINGSTON.
CARBURETER.
APPLICATION FILED JAN. 5, 1912.

1,168,513. Patented Jan. 18, 1916.
3 SHEETS—SHEET 2.

Fig. 2.



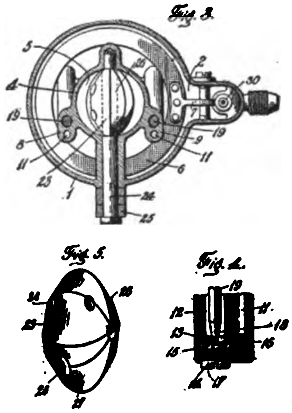
Witnesses
Chas. W. Stauffiger.
Jas. M. Davis

Inventor
George Kingston,
By [signature]
Attorney

G. KINGSTON.
CARBURETER.
APPLICATION FILED JAN. 5, 1912.

1,168,513. Patented Jan. 18, 1916.
3 SHEETS—SHEET 3.

Fig. 3. Fig. 5. Fig. 4.



Witnesses
Chas. W. Stauffiger.
Jas. M. Davis

Inventor
George Kingston,
By [signature]
Attorney

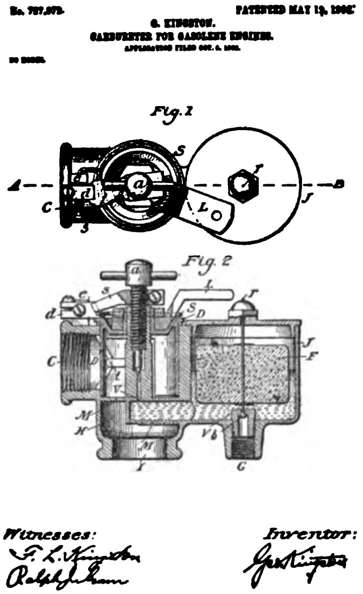
ellipsoidal, so that when closed it fills the passage completely shutting off one fuel inlet but allowing the other to act for idling by a notch opening.

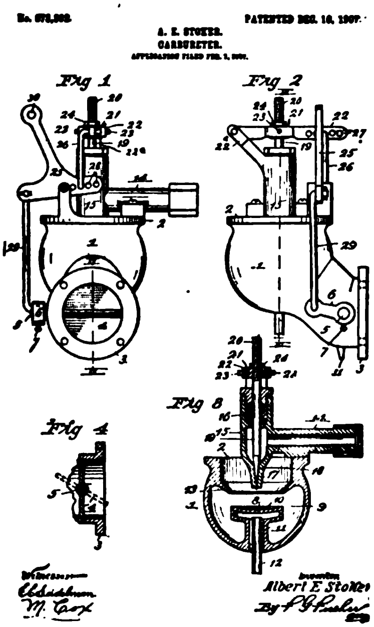
Class 11—Carburetors, proportioning flow, aspirating, single or multiple fuel inlets with regulating valves, single or multiple fixed air inlets.—All the classes and subclasses so far examined had fuel inlets, the area of which did not vary with flow, all changes of fuel flow were necessarily the result of corresponding changes in the vacuum due to the air flow, and any departure from constancy of proportion remained uncorrected, or some compensation by suitable control of the air-flow area or the fuel head was introduced. The remaining classes and subclasses, beginning with this one, are all characterized by regulating fuel valves, however actuated or associated with air inlets, fixed or valved for regulation. This class itself includes all cases of regulating fuel valves used in conjunction with fixed-air passages. It is clearly possible to secure proportionality or proper compensation by varying the fuel-inlet area, increasing it where the flow is insufficient due to a low air vacuum, and decreasing it otherwise, but, as in other cases, the real problem is one of degree, because the area adjustment must be just right in amount. Moreover, the fuel-inlet area is always extremely small in proportion to that for the air, and especially so in carburetors where a very high vacuum is used to induce flow, so that any fuel-inlet adjustment must be extremely precise and fine in comparison with an equivalent air-area adjustment.

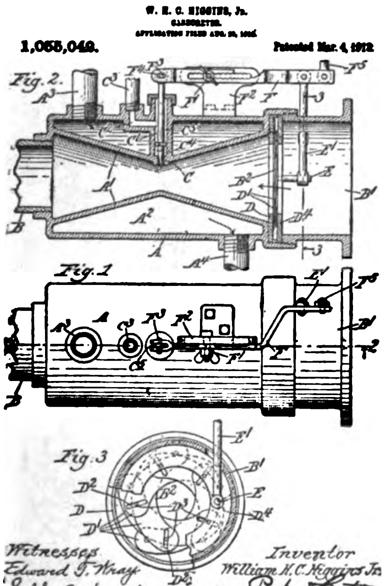
The cases of this class are grouped under several subclasses and will be examined under their several group headings.

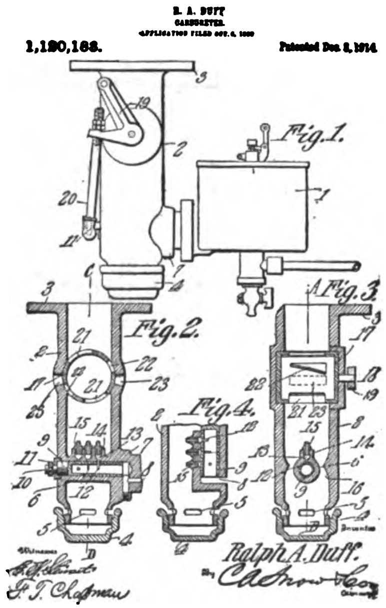
Subclass 11.1—Single fuel-inlet valve, throttle control.—On page 359 (727,972, May 12, 1903, Kingston) rotation of the barrel-throttle lifts the fuel-needle valve by rotating it in its fixed screw-threaded casing. No direct reliance is placed on vacuum control of proportionality, but the idea is that proportionality of flow should follow proportionality of areas provided for fuel and air or mixture flow, respectively, which, of course, is not feasible at all for variable speed engines and questionable even for those of constant speed. The same idea is involved in the form on page 359 (873,392, Dec. 10, 1907, Stoker), where the fuel-needle valve is lifted by a link from the throttle as the latter opens, and on page 359 (1,055,042, Mar. 4, 1913, Higgins), which has an iris throttle and an adjustable fulcrum-needle valve-lifting lever. A rotating fuel valve regulating three fuel inlets, equivalent to one, by a throttle linkage is shown on page 359 (1,120,183, Dec. 8, 1914, Duff), and having as well a throttle-controlled secondary air inlet. Another form that merely illustrates the cam idea of securing any desired numerical relation between the fuel area and that for air or mixture flow is shown on page 360 (1,124,697, Jan. 12, 1915, Carter).

Subclass 11.2—Single fuel inlet, independently controlled by air flow or vacuum.—One fairly old case, that on page 361 (725,741, Apr. 21, 1903, Miller), indicates an appreciation of the desirability of regulating the fuel flow by adjusting its area to some prime variable of air flow. In this case air volume and velocity constitute the variable to actuate a fan-blade type of air motor, which in turn rotates a flyball governor, and this in lifting opens the fuel needle, a


G. KINGSTON.
CARBURETER FOR GASOLENE ENGINES.
Fig. 1
Fig. 2
Witnesses:
Inventor:

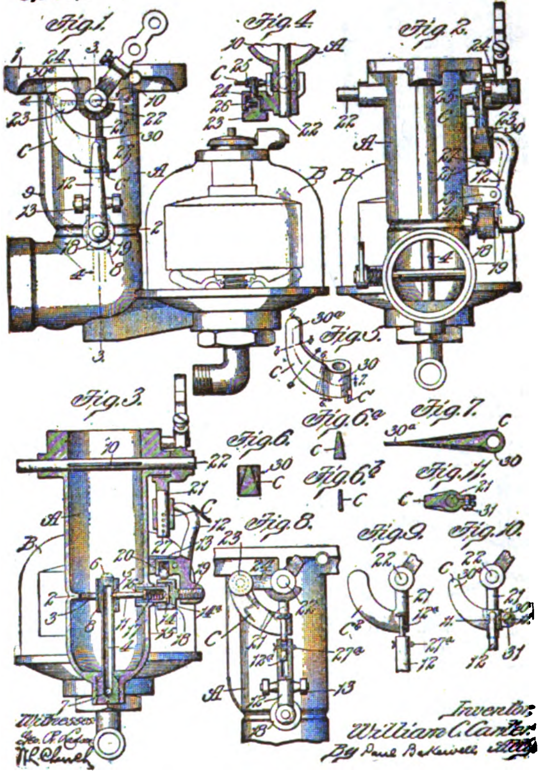

A. E. STOKES.
CARBURETER.
Fig 1
Fig 2
Fig 3
Fig 4
Albert E Stokes


W. H. C. HIGGINS, Jr.
CARBURETER.
Fig. 2.
Fig. 1
Fig. 3
Witnesses
Edward T. Wray
Inventor
William H. C. Higgins Jr.
by Parker & Burton
Attorneys.


R. A. DUFF
CARBURETER.
Fig. 1.
Fig. 2.
Fig. 3
Fig. 4.
Ralph A. Duff.
F. T. Chapman

W. C. CARTER.
NEEDLE VALVE OPERATING MECHANISM FOR CARBURETERS.
APPLICATION FILED OCT. 2, 1911.

1,124,697. Patented Jan. 12, 1915.



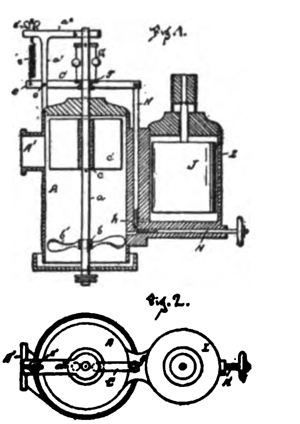
No. 726,941. PATENTED APR. 21, 1903.

C. A. MILLER.

FUEL FEED REGULATOR FOR EXPLOSIVE ENGINES.

APPLICATION FILED MAR. 1, 1902.

NO MODEL.



Witnesses: Charles A. Miller. Inventor

By Attorney

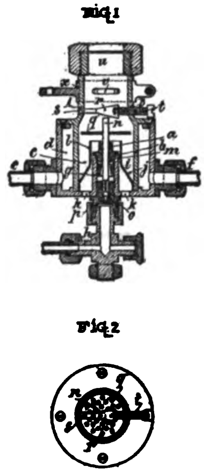
No. 746,110. PATENTED DEC. 8, 1903.

F. & G. LONGUEMARE.

CARBURETER FOR EXPLOSIVE MOTORS.

APPLICATION FILED OCT. 15, 1902.

NO MODEL.



Witnesses Inventors

By Attorney

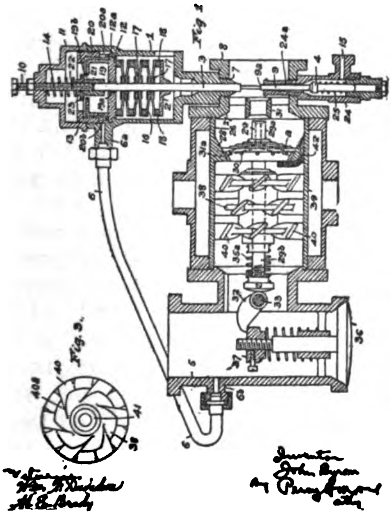
J. BYRON.

CARBURETER.

APPLICATION FILED JUNE 6, 1912.

1,065,508. Patented June 24, 1912.

2 SHEETS—SHEET 1.



Witnesses: Inventor John Byron

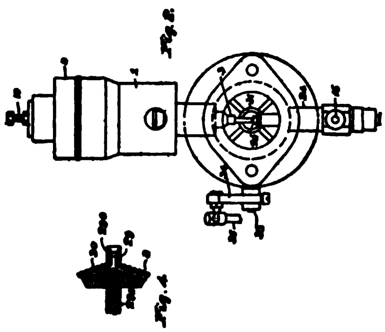
J. BYRON.

CARBURETER.

APPLICATION FILED JUNE 6, 1912.

1,065,508. Patented June 24, 1912.

2 SHEETS—SHEET 2.



Witnesses: Inventor John Byron

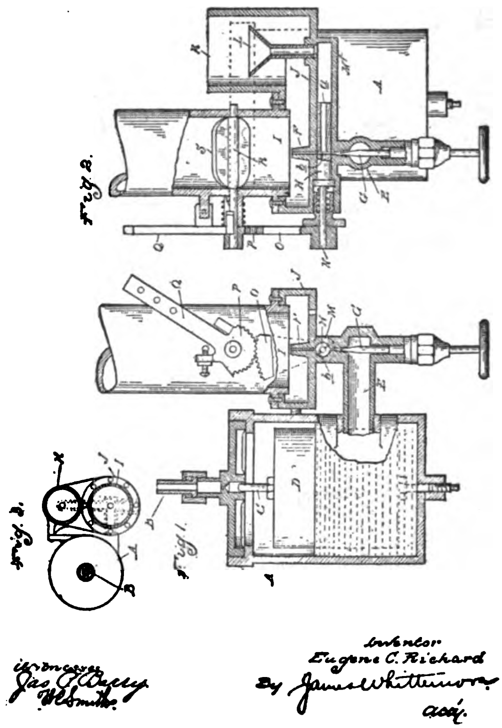
No. 771,098. PATENTED SEPT. 27, 1904.

E. C. RICHARD.

CARBURETER FOR EXPLOSION ENGINES.

APPLICATION FILED JAN. 11, 1904.

NO MODEL.



somewhat roundabout procedure rather full of mechanical difficulties. A more direct action is provided in the form on page 361 (746,119, Dec. 8, 1903, Longumare & Longumare), where the fuel needle is lifted by a perforated flow disk raised by air velocity, the lift of which can not be graduated properly without some more definite provisions than shown, in fact it is questionable whether this is a regulating needle at all or merely a fuel stop or check valve of class 1. A long tapered fuel needle is actuated by the vacuum beyond the throttle or air valve, by a sort of bellows type of diaphragm, on page 361. (1,065,503, June 24, 1913, Byron.) The fuel valve is placed before the air valve which acts as throttle, and a series of mixing baffles are located beyond for mixing. The case is interesting mainly as an example of direct vacuum control of a fuel-needle valve.

Subclass 11.3—Mixed flow.—One case only will serve to illustrate mixed flow compensation, in connection with a regulating-fuel valve having the same object, that on page 362. (771,096, Sept. 27, 1904, Richard.) The fuel valve is a rotating plug, gear connected to the throttle, fuel from the float chamber and air from the main intake are brought to a common point, flowing together to the fuel nozzle as the fuel valve may permit a somewhat queer complexity.

Class 12—Carburetors, proportioning flow, aspirating, single fuel and air inlets, both with regulating valves.—In point of numbers this is about the largest of the classes, indicating the popularity of the idea of control of both quantity and proportionality by two valves, one for fuel and the other for air, by their respective areas. As a class it is both old and new, the difference being in the means of actuating the two valves or in relating them to each other as will appear in the subclasses, some of which are typically old, and others mainly recent. In many cases the idea of flow-area control of quantities has led to a neglect of the equally potent influence of vacuum, put in general such mistakes belong to the older cases though, of course, some persist as inventors are not necessarily well informed.

A few cases are grouped under the general headings because of difficulty in meeting the subclass definitions with precision, and one of these is shown on page 370. (973,855, Oct. 25, 1910, Cannon.) A rotating sleeve throttle for a fixed air passage moves a rotating cap over an arc-shaped fuel slot to regulate the fuel valve with the throttle, but auxiliary air is admitted through another throttle port, after passing an automatic valve, controlled by the exhaust back pressure or a pump delivery pressure, acting on a diaphragm. Another such mixed case is that on page 370 (1,045,251, Nov. 26, 1912, Bourne), where the essential feature is a level tilting control of a fuel-needle valve by a pendulum, as the body of the carburetor changes level. On page 370 (1,061,995, May 20, 1913, Erickson), the fuel and air valves are controlled together, partly by the vacuum and partly by a centrifugal ball governor driven by an air motor in the main stream. A power-driven shaft carries a fan and a centrifugal ball governor, the former controlling the air drawn through an automatic valve, and the latter controlling the fuel needle, as shown in the combination shown on page 371 (1,123,876, Jan. 5, 1915, Hiddleson), which is somewhat questionable as a proportioning flow carburetor, but suggestive.

Two ideas are illustrated in the costruction on page 371 (1,169,574, Jan. 25, 1916, Schulz), a recent case—first, the combination of the throttle and the automatic air-inlet valve carrying the fuel needle, and, second, the formation of a series of more or less parallel thin baffles to act as fuel lifters and sprayers. With reference to the latter point, it is clear that some definite means of lifting the fuel above the air valve and throttle from the fuel nozzle is necessary, because the nozzle is located in a region of very low vacuum and low air velocity. Here the baffles serve as inclined planes up which the fuel is swept by the air flow concentrated between them and moving at velocities that do not vary as much as in the main air passage, because as air flow increases and the valve lifts, more of these cross-flow passages come into action. While the proportionality characteristics of this air valve is free, the interference with its lift by the cam acting on the stem to serve as throttle reduces the case to one of throttle control with different proportionality characteristics.

Subclass 12.1—Valved fuel inlet beyond air-inlet valve acting as throttle, fuel valve controlled by air valve.—Mechanically, this is a very simple combination, applicable to only constant-speed engines with any hope of success, but not at all useful for variable-speed engines, as the variations of vacuum on the fuel inlet tend to upset and interfere with area adjustments. One of the early cases intended for stationary engines is that on page 372. (623,568, Apr. 25, 1899, Secor.) This has two cocks, one for fuel and one for air, controlled by the governor and linked together. A rotating slide air valve linked to a lifting fuel needle produces similar results, as shown on page 372. (654,894, July 31, 1900, Hasbrouck.) A rotating screw-threaded fuel needle linked to an air plug cock is shown on page 372 (695,060, Mar. 11, 1902, Krastin), and a screw-threaded rotating air valve carrying a fuel needle valve, both moving together toward or away from their respective seats fixed in the casing, is shown on page 372 (711,902, Oct. 21, 1902, Leppo & Leppo). A rotating cylindrical sleeve form of air valve carrying a fuel needle threaded into a fixed seat is the mechanism on page 373. (745,063, Nov. 24, 1903, Jenness.) Two long taper valves, one for air and the other for fuel, fastened together and moved mechanically as one, constitute the form on page 373. (791,810, June 6, 1905, Orr.) A screw-threaded fuel valve geared to a rotating air slide is shown on page 373. (816,477, Mar. 27, 1906, Kellogg.) A tapering arc slot form of fuel valve on a rotating spindle has a cam connection to a swing type of air valve, in the form shown on page 374. (909,490, Jan. 12, 1909, Westaway.) The iris air valve linked to a threaded fuel needle is shown on page 374. (926,039, June 22, 1909, Warren.)

Adaptability of the fuel valve linked to an air valve in front of it, to the two-cycle engine transfer port is shown on page 374. (1,013,955, Jan. 9, 1912, Roberts.) In this case the air valve is of the curved swing-check form, and the fuel inlet is located in a bend so that the passing air always sweeps the fuel nozzle. This arrangement, like many others illustrated, keeps the crank case free of mixture, a matter of very considerable importance with the less volatile fuels. A long tapered fuel needle carried in the stem of an air poppet valve, flat seated, both moving mechanically as one, is shown

on page 375. (1,028,723, June 4, 1912, Hezinger.) Another form of the longer tapered fuel needle carried by a flat-seated air valve but of different shape is shown on page 375. (1,086,594, Feb. 10, 1914, Goldberg.) Still another such fuel valve, but associated with a tapered air valve, is shown on pages 375 and 376. (1,145,824, July 6, 1915, Udale.) A cam connection of fuel needle to a barrel air valve is shown on page 376. (1,172,595, Feb. 22, 1916, Heath & Taylor.)

The present-day tendency to seek fuel passages having definite regular flow laws to be associated with structures giving similarly definite relations between flow and vacuum is again illustrated in the following case of another form of capillary fuel-flow passage, the outlet from which is controlled by a fuel valve moving with the air valve. On pages 376 and 377 (1,190,124, July 4, 1916, Lukacsevics & Terrill) a fibrous pad is inserted in the ports of the annular fuel passage, resisting the fuel flow under the influence of the vacuum so that it follows the capillary law with respect to pressure, the exposed fuel-flow area varies with the air-flow area by the movement of a pair of sleeve valves.

Subclass 12.2—Valved fuel inlet between air inlet valve and throttle, both fuel and air valves controlled by the throttle.—The location of the fuel inlet, typical of this class, between the air valve and the throttle represents a conscious effort to control the vacuum at the fuel valve as it could not be controlled in the last subclass, but the linkage of both the air and the fuel valve to the throttle, while giving somewhat better control, is poorly adapted to variable-speed engines though quite a satisfactory and much-used arrangement with stationary engines.

A rotating cylindrical barrel with two opposite ports, one for air and the other serving as throttle with the fuel inlet in its body and a threaded fuel valve actuated by the same movement, is one very simple form of this type and is shown on page 378. (795,357, July 25, 1905, Maxwell.) Two poppets, one air and one throttle, with a fuel needle valve between, are all operated together by cams on page 378. (805,979, Nov. 28, 1905, Menges.) The combination of a damper throttle with a cam-actuated fuel needle *and* a rotating flat air valve is shown on pages 378 and 379. (848,425, Mar. 26, 1907, Anderson.) Another case of sleeve barrel, acting as air valve and throttle on opposite edges, is shown on page 379 (883,740, Apr. 7, 1908, Poppe) with a slide form of fuel valve in the center. Two damper valves and a threaded fuel needle between them are shown linked together on page 379. (910,326, Jan. 19, 1909, Stevenson.) An old form of annular tapered air valve linked to a damper throttle and carrying a fuel needle actuating cam, is shown on page 379. (983,247, Jan. 31, 1911, Miller.) A series of three linked dampers with a cam-actuated fuel needle is shown on page 380 (1,011,696, Dec. 12, 1911, Winton) with a by-pass air and fuel passage leading to a point between the second and third dampers as an idling yet. Two dampers on the same spindle with the fuel inlet in a return bend, its valve being cam connected to the air and throttle spindle, is shown in 1,033,886, July 30, 1912, Gentle.

A piston sliding in a cylindrical passage with side ports acts as both air valve and throttle, and moving on a ported hollow rod which is the fuel-supply passage, successively opening a series of holes to

increase the fuel area is illustrated on pages 380 and 381. (1,080,815, Dec. 9, 1913, Everest.) A rotating cylindrical sleeve acting as air valve and throttle is shown on page 381. (1,085,003, Jan. 20, 1914, Austin), carrying a fuel valve cam on one edge formed by tapering it. Another multiported fuel valve, this time with a helically slotted sleeve linked to a pair of damper valves, is shown on page 381. (1,125,069, Jan. 19, 1915, Coulter.) The combination of long tapered fuel needle and tapered air throat, with the air valve, the needle, and the throttle moving together is shown on pages 381 and 382. (1,143,-511, June 15, 1915, Cox.) A later form of the plug valve serving as both air valve and throttle with a fuel inlet in the middle is shown on pages 382 and 383. (1,183,587, May 16, 1916, Parkin.) In this case the fuel has the sliding sleeve form, is cam operated, and a separate idling jet is provided, leading directly from the float chamber. It is interesting to compare this with the early case on page 378 (795,357, Maxwell).

Subclass 12.3, valved fuel inlet at or in front of air valve acting as throttle, fuel valve controlled by air valve.—When the fuel inlet is in front of the air valve or just in line it receives none of the vacuum due to air entrance which is so high when the valve is closed, and which makes fuel regulation so difficult. Located thus, the fuel flow is induced wholly by the velocity head vacuum of the air or substantially so, and the addition of a fuel valve gives wider scope in location and compensation, though it is clear that there is no essential relation between the two areas, air and fuel, when the speed is variable. On page 384 (930,724, Aug. 10, 1909, Boore) rotating slotted cone acts as air valve, and its movement also actuated the fuel valve which is in front and receives only the vacuum of air flow before entrance. One odd form is that on page 385 (977,044, Nov. 29, 1910, Rebourg), where a warped surface constitutes a variable tapered throat at the small diameter of which the fuel inlet is located. The fuel valve of sleeve type is actuated by the same movement as varies the air throat. A fuel needle valve is attached to an air slide on page 385 (1,053,136, Feb. 11, 1913, Daellenbach), and operated with the throttle, but it is not clear how this can have any influence. A recent form, that on pages 385 and 386 (1,184,923, May 30, 1916, Carter), provides a cam connection between the fuel needle and a damper, but adds, what is characteristic of the later days of heavy fuel, a low-speed lifting tube for the main jet above the throttle.

Subclass 12.4—Valved fuel inlet between automatic air inlet valve and throttle, fuel valve controlled by throttle.—Air admission through an automatic valve is the direct means of preventing much rise of vacuum beyond it as air flow increases, and if gravity loaded the rise may be regarded as practically nothing, though, of course, variably loaded valves with springs may be made to build up vacuum to any desired degree. Association of a fuel valve with an automatic air inlet is a logical thing, especially so if the valve is of the sort that limits the vacuum change to a small value, because in this case the vacuum will not increase enough with air flow to produce a sufficient fuel flow, so an increase of fuel-flow area is the natural and proper correction. It is not, however, at all logical to associate this fuel-valve movement and flow-area increase with the throttle, because throttle position does not determine flow rate any more than speed in general practice, though, of course, there is a closer, indirect relation

for the constant-speed class of engine. This being the case, one would expect the carburetors of this class to be designed for constant-speed engines only, yet such is not the case.

In the form shown on page 387 (755,074, Mar. 22, 1904, Sturtevant & Sturtevant) air enters through an automatic spring-loaded valve, and the fuel needle is linked to the throttle. A separate fuel and air inlet for idling by-passes the throttle. An illustration of the stationary-engine adoption of this sort of arrangement is given on page 387 (947,633, Jan. 25, 1910, Brady), where an ordinary fly-ball governing throttle on the mixture-inlet pipe has also a connection to the fuel valve, so throttle and fuel valve vary together, air entering the mixing chamber through an automatic air-check valve. This case also illustrates the heating of such a mixing chamber by exhaust gases to promote vaporization, which when carried out to the necessary degree becomes a means of conversion of a gasoline into a heavier oil engine. A direct cam connection between a damper throttle and the fuel needle is shown on page 388 (961,590, June 14, 1910, England), with an automatic air inlet. Another form involving double-swing type of automatic air valves, and a sliding form of fuel valve formed by a slot in a sleeve with sliding plunger operated from the throttle, is shown on page 388. (1,066,608, July 8, 1913, Harris.) An arrangement of the air inlet to develop the maximum-velocity action at the jet without flow-entrance resistance and its building up of vacuum is shown on pages 388 and 389. (1,042,982 originally, reissued as 13,837, Dec. 1, 1914, Sliger.) Location of the fuel valve within the stem of the throttle, associated with an automatic main air-inlet valve, is illustrated on page 389. (1,132,314, Mar. 16, 1915, Eiker.)

Subclass 12.5—valved fuel inlet between automatic air-inlet valve and throttle, fuel valve controlled by automatic air valve.—As a simple logical arrangement for securing not only the desired proportionality control but also the least entrance resistance and maximum density of mixture, nothing appeals so directly and strongly as this. The large number of cases in the subclass is itself an indication that this fact is becoming appreciated, especially as so many are comparatively recent, and there is every evidence that this subclass will displace in interest and use the former popular subclass, 8.2, of fixed fuel and primary air with automatic secondary air.

While the general idea of actuating a fuel valve by an automatic air valve is very old, the germ being found in those cases of class 1 developed directly from the natural-gas mechanism of stationary engines and first used with pressure fuel supplies. The appreciation of requirements for suitable and proper graduation in the interest of proportionality and least pressure drop is comparatively recent, and its growth can be traced in the cases of this subclass fairly well.

The first case, that on page 390 (770,559, Sept. 20, 1904, Clay), shows a spring loaded air check valve with the fuel valve in front of it where the vacuum inducing fuel flow is very small, but the mixture entering the air valve suffers a considerable and increasing pressure drop. However, the long taper needle now generally called a "metering pin" is clearly shown, and the valve seat has a small angle taper showing an understanding of the relation between axial movement and area and the necessity for considerable movement for precise graduation. Many later forms fail in some of these points of

construction. An indirect movement of a common form of fuel needle through a cam by a spring-loaded automatic valve is shown on page 390. (807,479, Dec. 19, 1905, Mason.) On page 390 (818,853, Apr. 24, 1906, Renault) a form of sliding fuel valve is used, but the automatic air valve is gravity loaded as is proper for the case, and, even though it has sharp edges with a low coefficient of efflux, it is provided with a long slight taper seat, the good effects of which are largely destroyed by the restriction about the spraying cone. A return to the long fuel-metering pin and its association with a gravity-loaded long-taper automatic air valve is shown on page 391. (826,531, July 24, 1906, Briest.) A gravity swing check actuating an ordinary needle is shown on page 393 (892,155, June 30, 1908, Hodges), and a lever-operated metering pin linked to a spring-loaded automatic air valve on page 393 (926,848, July 6, 1909, Carlson). Another form of swing air check, gravity loaded, is shown on page 393 (895,709, Aug. 11, 1908, Abernethy & Abernethy), this time associated with a rotating plug fuel valve, that constitues the spindle of the air valve. A fuel valve consisting of a pair of flat sector slides moving over a circular row of fuel orifices is shown on page 393. (941,424, Nov. 30, 1909, Leonard.) The fuel valve movement is produced by a helically twisted stem of the spring loaded automatic air valve as it lifts. An annular automatic air valve, spring loaded, is shown as lifting a very long fuel-metering pin, at the lower end of which is a dash pot piston in the fuel on page 394. (971,038, Sept. 27, 1910, Gulick.)

The problem of lifting the fuel in such low-velocity air streams as are typical of this class is recognized on page 395 (984,874, Feb. 21, 1911, Winton), which places the fuel valve at a high point and operates it by a yoke from the stem of a spring-loaded air valve with a liquid dashpot. This same lifting problem is attacked differently on page 395 (995,623, June 20, 1911, Miller), which has the low-speed lifting tube above the throttle as found in other classes. Here the automatic air valve is of the swing-check form and operates the fuel valve by a cam. A piston form of gravity-loaded automatic air valve carrying a fuel-metering pin on one side and having a separate low-speed fixed jet, is shown on page 395. (1,006,411, Oct. 17, 1911, Scott.) A long-taper gravity-loaded air valve rising in a narrow seat and guided by a fixed central spindle carries a tube at the lowest point of its stem, into which projects a fixed tapered fuel pin, as shown on page 396. (1,010,003, Nov. 28, 1911, Stewart.) The lifting problem is attacked by passing some air directly across the fuel-lifting tube to produce the necessary aspirating effect. The stem itself contitutes a dashpot plunger. On page 396 (1,032,307, July 9, 1912, Stewart) the metering pin is moved to the air-valve head and the fuel is discharged through radial holes into the stream of air, while on page 396 (1,049,417, Jan. 7, 1913, Stewart) the fuel valve is located in a side pocket open to the atmosphere and is actuated from the air valve by a lever. From this pocket all the measured fuel and some atmospheric air that has not been measured by the air valve are carried above the throttle, being heated by the exhaust on the way. Of course, with a wide-open throttle and low engine speeds there is no assurance that there would be sufficient vacuum to lift fuel in this way as high as might be necessary.

A long metering pin fixed in a long-taper hollow air-valve stem, gravity loaded, discharges its fuel directly into the air-valve seat where, of course, the velocity is greatest on pages 396 and 397. (1,050,059, Jan. 7, 1913, Gould.) An odd form of gravity-loaded air valve, lifted indirectly by the vacuum, is shown on page 397 (1,088,231, Feb. 24, 1914, Lawrence), which carries the metering pin on its end directly in the air path. On page 397 (1,115,951, Nov. 3, 1914, Martin) the fuel inlet is in the form of a straight slot exposed in varying degree by a piston form of automatic air valve, spring loaded. The metering pin itself is formed on the end of the air-valve stem on page 398 (1,120,128, Dec. 8, 1914, Browne) and lifts by aspiration through the hollow portion of the stem above, discharging at the air-valve seat radially. An electrical fuel heater is also provided.

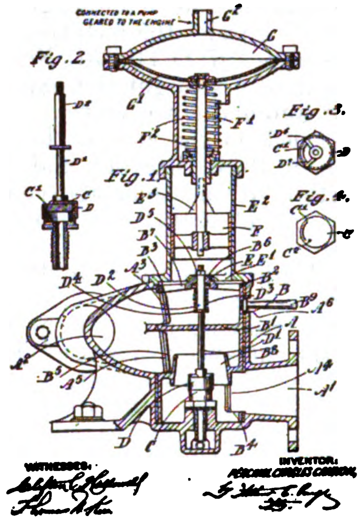
Two automatic air valves, both spring loaded, join their air streams and therefore act as one on page 398. (1,123,048, Dec. 29, 1914, Washburn.) One of them lifts the fuel-metering pin and the fuel escapes into the combined air stream at the entrance to a sort of choke tube. A recent case, on pages 398 and 399 (1,130,350, Mar. 2, 1915, Thompson), uses a gravity-loaded hollow piston with tapered entrance, in the center of which is fixed a tapered plug carrying the fuel passage. The metering pin is in its top and lifts with the piston through a cam, permitting the fuel to flow radially into the high-velocity air. A pair of swing checks on opening lift the metering pin, so fuel is discharged directly in the path of the high-velocity air in the form shown on page 399. (1,143,779, June 22, 1915, Pembroke.)

An unusual form of heavy double air valve, gravity loaded, with a central fixed metering pin and air valve seat discharge, is shown on page 399 (1,145,172, July 6, 1915, Speed), also provided with ball-valved dashpot. Another case of fixed central coincal taper plug, this time with a cylindrical sleeve valve lifting around it by the action of the vacuum on a gravity loaded annular piston, is shown on page 400. (1,149,291, Aug. 10, 1915, Richard). The metering pin is given a peculiar curved form necessary for proportionality with this form of air valve, instead of curving the air valve itself or its seat. A small idling air hole is provided at a throttle slide. An adjustably fixed metering pin, seated in a hole in the stem of a gravity loaded air valve, is shown on page 400 (1,159,029, Nov. 2, 1915, Hodges), the fuel lifting being accomplished at low speeds by a fixed by-pass for aspirating air.

Direct lift of a multiorificed sleeve form of fuel valve, by the movement of a swing air check, directing the air across it, is illustrated on page 400. (1,162,680, Nov. 30, 1915, Buick.) Incorporation of the dashpot within the gravity air valve, and the use of mercury for loading it, are illustrated on page 401. (1,172,397, Feb. 22, 1916, Shulz.) These features are associated with a lever operated metering pin at the side, discharging at orifices around the air valve seat in the path of the entering air. A case of indirect action is that on page 401 (1,179,568, Apr. 18, 1916, Shortt), which has two diaphragms, one operating the air inlet, and another valve in series with it having fuel orifices in its seat. A threaded needle valve is rotated with the air inlet valve.

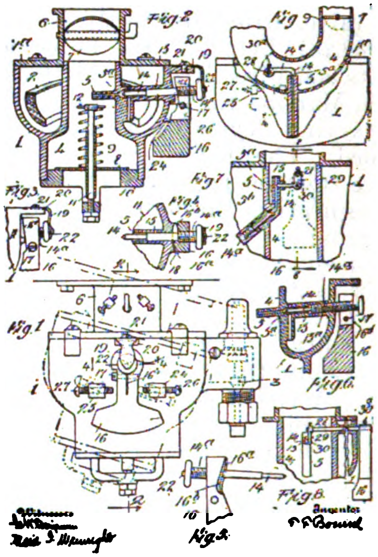
CARBURETER.

973,855. Patented Oct. 25, 1910.



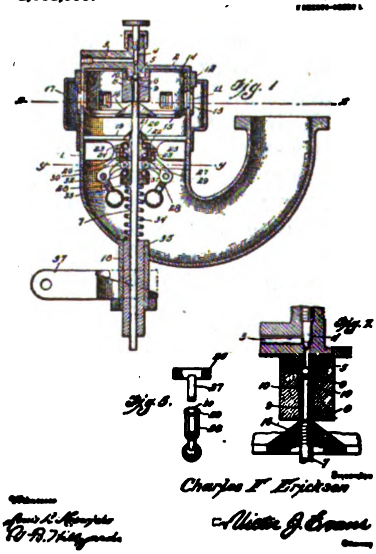
T. F. BOURNE.
CARBURETER.
APPLICATION FILED JUNE 15, 1912.

1,045,251. Patented Nov. 26, 1912.



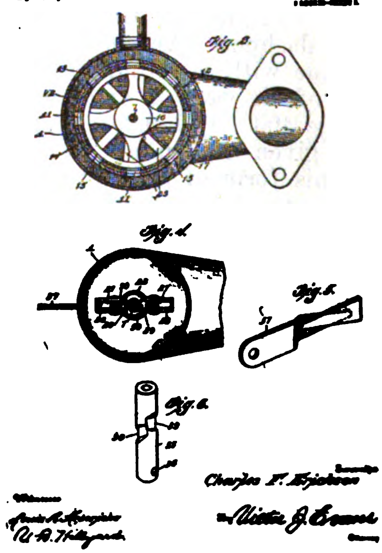
C. F. ERICKSON
CARBURETER.
APPLICATION FILED DEC. 6, 1911.

1,061,995. Patented May 20, 1913.



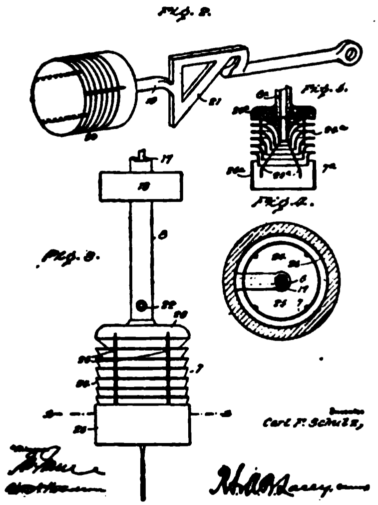
C. F. ERICKSON
CARBURETER.
APPLICATION FILED DEC. 6, 1911.

1,061,995. Patented May 20, 1913.



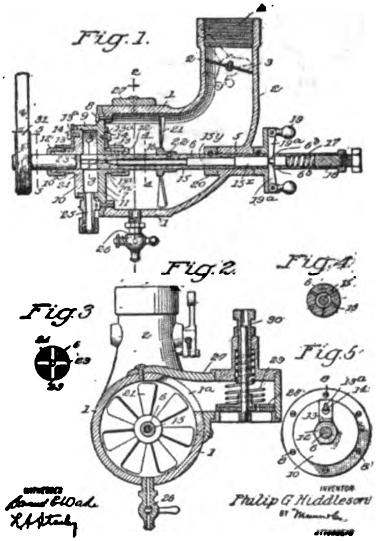
C. F. SCHULZ.
CARBURETER.

1,169,574. Patented Jan. 25, 1916.



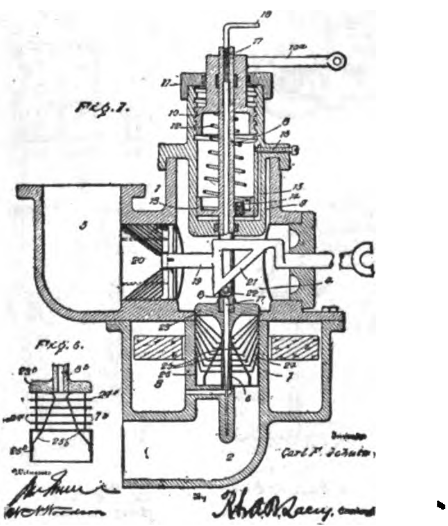
P. G. HIDDLESON.
CARBURETER.
APPLICATION FILED APR. 24, 1914.

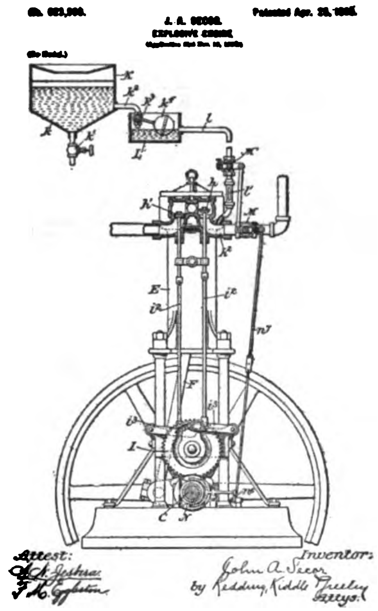
1,123,876. Patented Jan. 5, 1915.

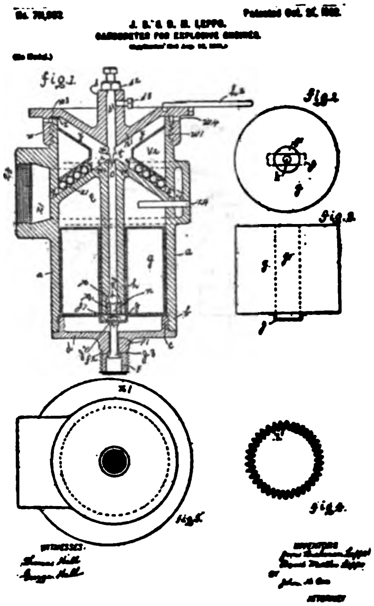


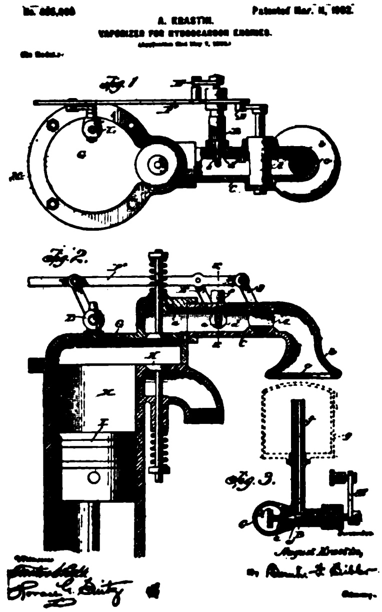
C. F. SCHULZ.
CARBURETER.

1,169,574. Patented Jan. 25, 1916.




EXPLOSIVE ENGINE.
Attest:
Inventor:
John A. Secor
by Redding, Kiddle & Greeley Attys.


CARBURETER FOR EXPLOSIVE ENGINES.
fig.1
fig.2
fig.3
fig.4
fig.6


A. KRASTIN.
VAPORIZER FOR HYDROCARBON ENGINES.
Fig. 1
Fig. 2.
Fig. 3.

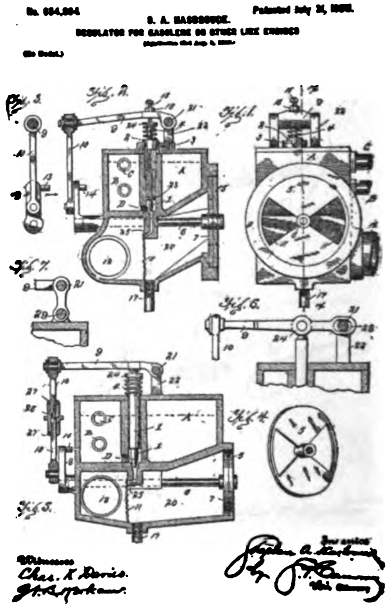
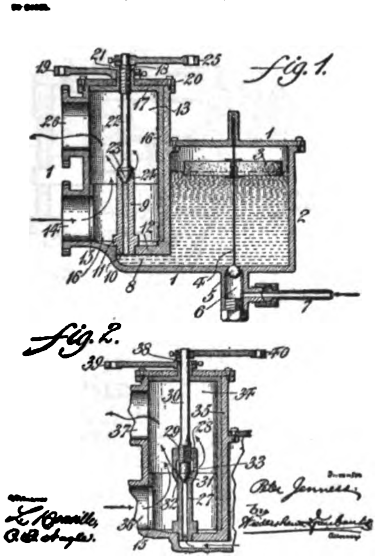
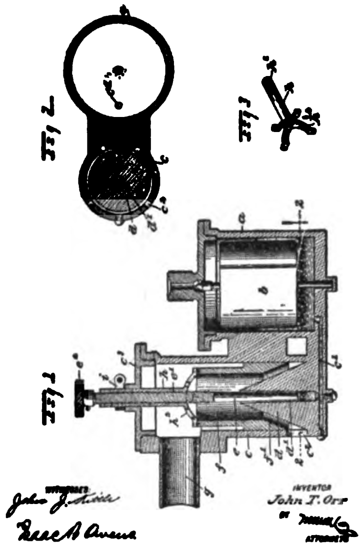


Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 6.
Fig. 7.
Chas. K. Davies.

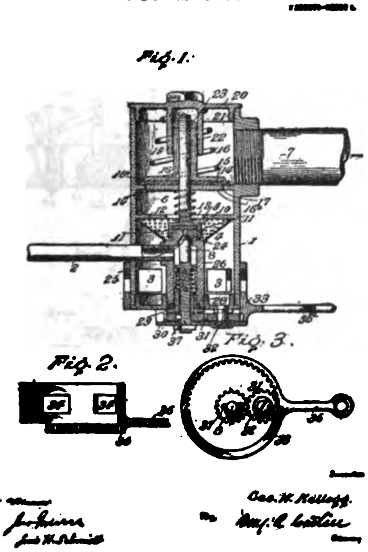
PATENTED NOV. 24, 1908.
CARBURETER FOR GASOLENE ENGINES.



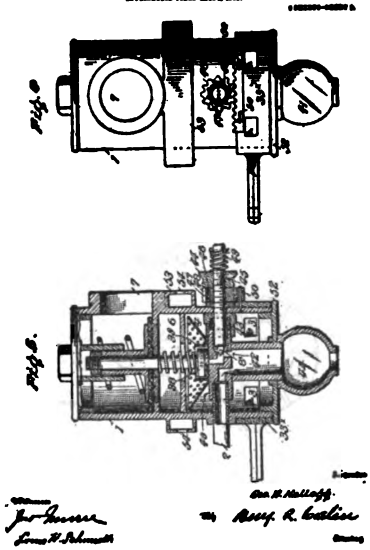
No. 901,310 PATENTED JUNE 8, 1909.
J. T. ORR.
CARBURETER.



PATENTED MAR. 27, 1906.
G. W. KELLOGG.
CARBURETER.

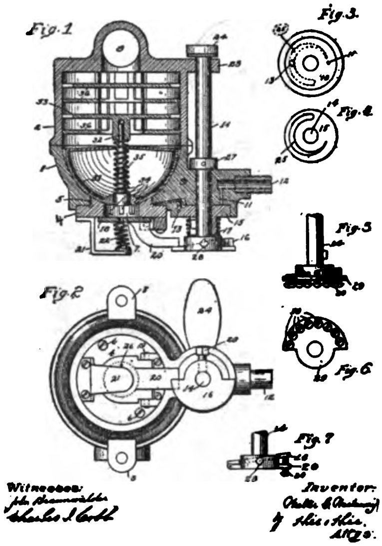


PATENTED MAR. 27, 1906.
G. W. KELLOGG.
CARBURETER.



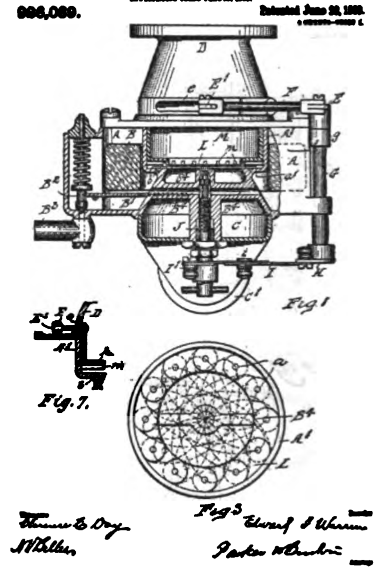
W. G. WESTAWAY.
CARBURETER.
APPLICATION FILED OCT. [illegible], 190[illegible].

909,490. Patented Jan. 12, 1909.



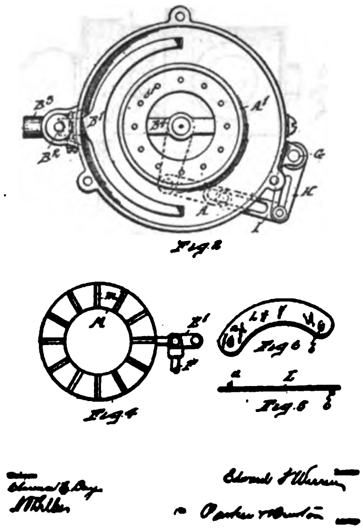
E. F. WARREN.
CARBURETER.
APPLICATION FILED [illegible]

996,089. Patented June [illegible], 1911.
2 SHEETS—SHEET 1.



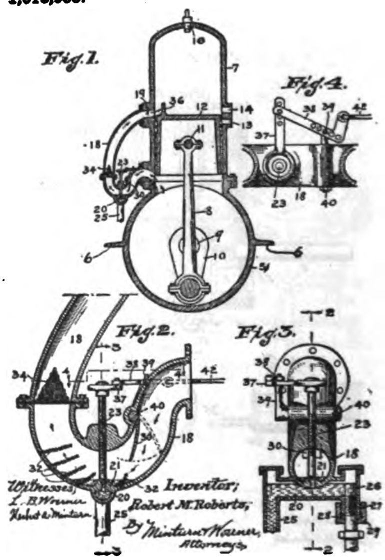
E. F. WARREN.
CARBURETER.
APPLICATION FILED JULY [illegible], 190[illegible].

996,089. Patented June [illegible], 1911.
2 SHEETS—SHEET 2.



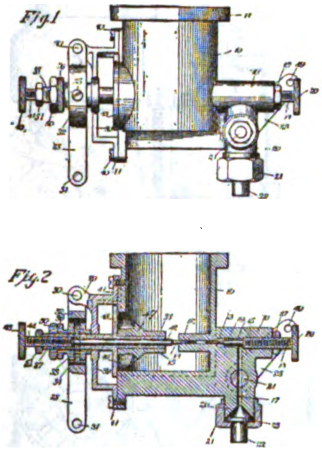
R. M. ROBERTS.
CARBURETER.
APPLICATION FILED AUG. [illegible], 1910.

1,018,965. Patented Jan. 2, 1912.



R. & G. ...
CARBURETER.
APPLICATION FILED MAY ..., 191...

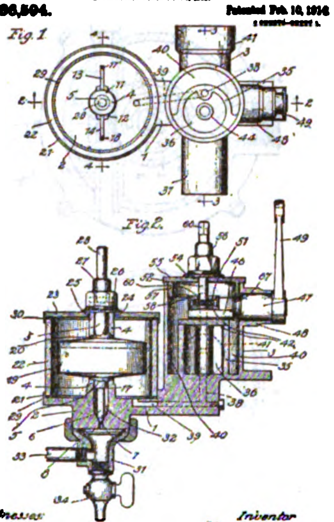
1,022,793. Patented June 4, 1912.



Witnesses
Inventors
Attorneys

J. S. GOLDBERG.
CARBURETER.
APPLICATION FILED NOV. ..., 19...

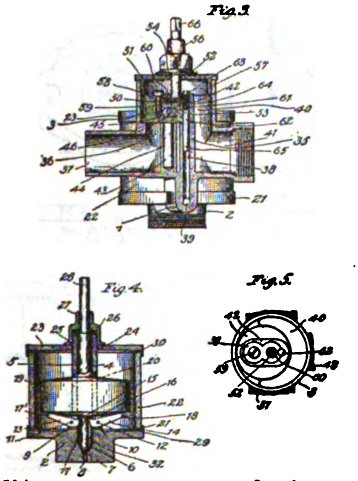
1,096,594. Patented Feb. 10, 1914.
2 SHEETS—SHEET 1.



Witnesses:
Leonard W. Novander.
George C. Heyborn
Inventor
John S. Goldberg
By Charles A. ...
Attorney

J. S. GOLDBERG.
CARBURETER.
APPLICATION FILED NOV. ..., 19...

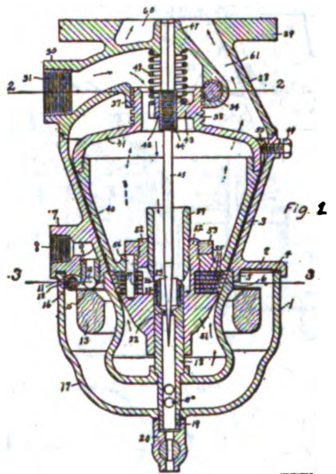
1,096,594. Patented Feb. 10, 1914.
2 SHEETS—SHEET 2.



Witnesses:
Leonard W. Novander.
George C. Heyborn.
Inventor
John S. Goldberg
By Charles A. ...
Attorney.

S. M. UDALE.
CARBURETER.
APPLICATION FILED DEC. ..., 1912.

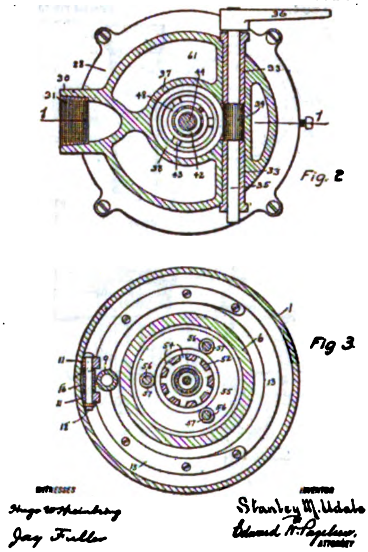
1,145,894. Patented July 6, 1915.
2 SHEETS—SHEET 1.



Witnesses
Jay Fuller
Inventor
Stanley M. Udale
Edward N. Pagelsen
Attorney

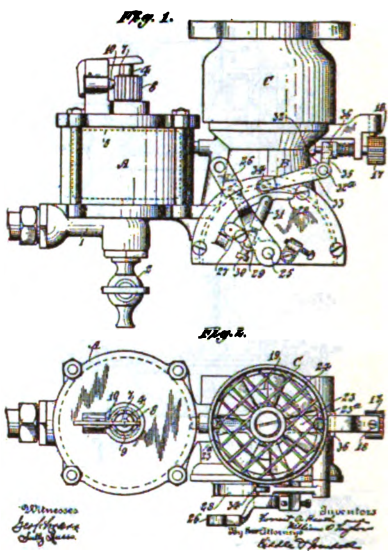
S. M. UDALE.
CARBURETER.

1,145,294. Patented July 6, 1915.



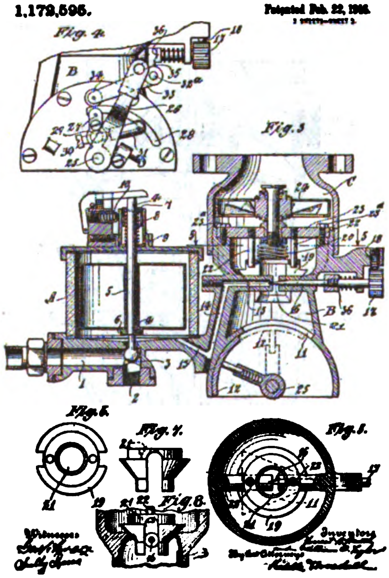
F. A. HEATH & W. G. TAYLOR.
CARBURETER.

1,172,595. Patented Feb. 22, 1916.



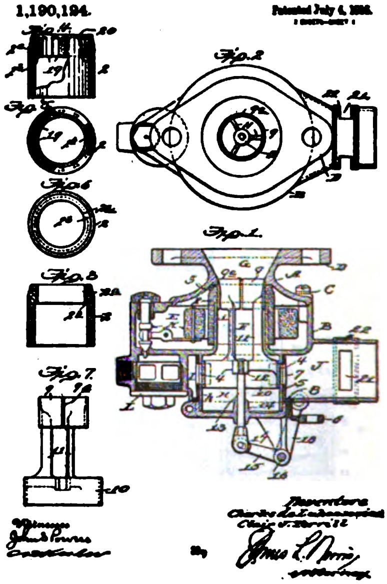
F. A. HEATH & W. G. TAYLOR.
CARBURETER.

1,172,595. Patented Feb. 22, 1916.



C. DE LUKACSEVICS & C. J. TERRILL.
CARBURETER.

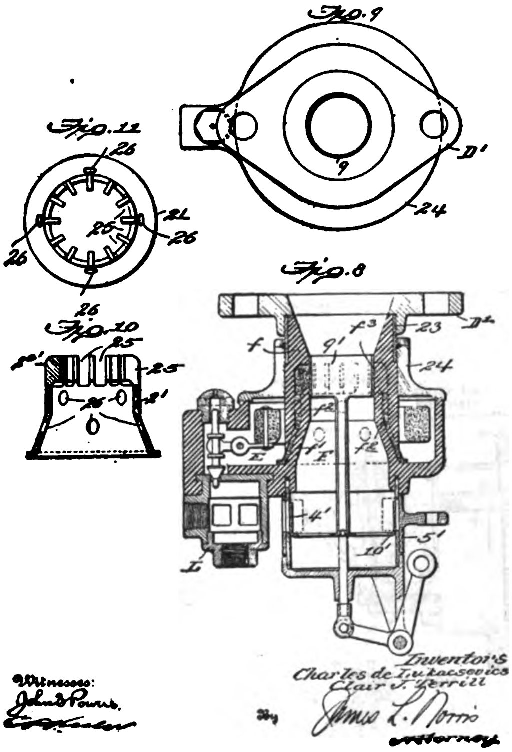
1,190,194. Patented July 4, 1916.



C. DE LUKACSEVICS & C. J. TERRILL.
CARBURETER.
APPLICATION FILED JULY 7, 1915.

1,190,124.

Patented July 4, 1916.
2 SHEETS—SHEET 2.



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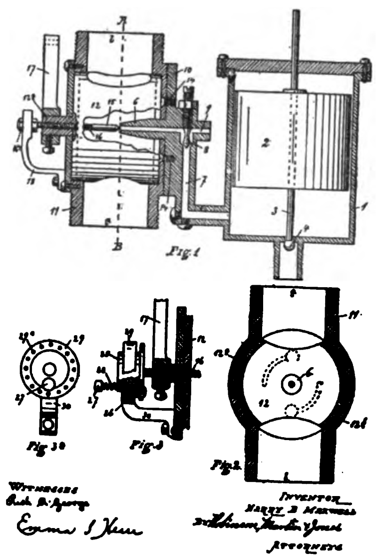
No. 796,597. PATENTED JULY 25, 1905.

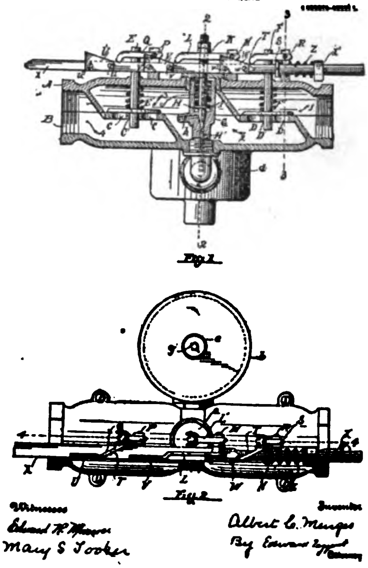
H. B. MAXWELL.
CARBURETER.
APPLICATION FILED FEB. 6, 1905.



No. 836,979. PATENTED NOV. 27, 1906.

A. C. MENGES.
CARBURETER.
APPLICATION FILED DEC. 22, 1904.

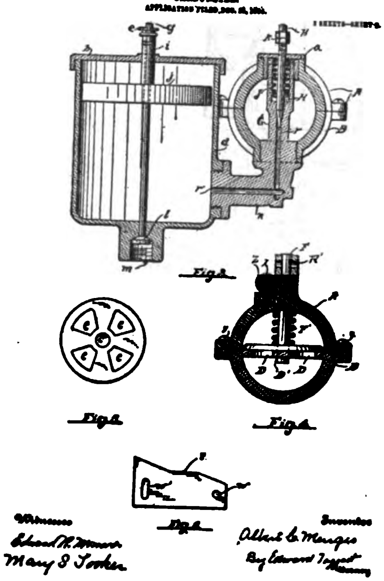
2 SHEETS—SHEET 1.



No. 836,979. PATENTED NOV. 27, 1906.

A. C. MENGES.
CARBURETER.
APPLICATION FILED DEC. 22, 1904.

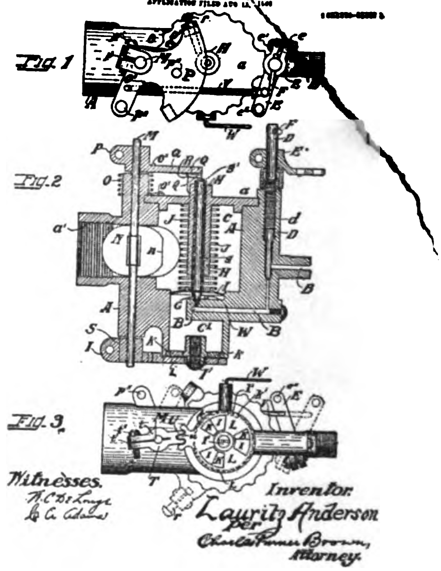
2 SHEETS—SHEET 2.



No. 848,625. PATENTED MAR. 26, 1907.

L. ANDERSON.
CARBURETER FOR GASOLENE ENGINES.
APPLICATION FILED AUG. 13, 1906.

2 SHEETS—SHEET 2.

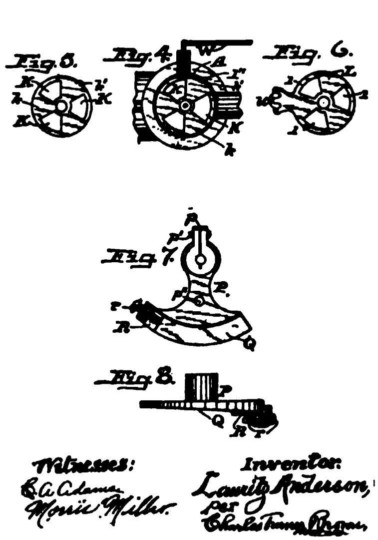


PATENTED MAR. 26, 1907.

L. ANDERSON.

CARBURETER FOR GASOLENE ENGINES.

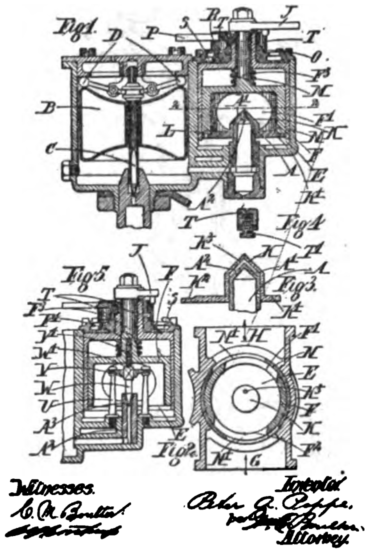
APPLICATION FILED AUG. 12, 1905.



PATENTED APR. 7, 1908.

P. A. POPPE.

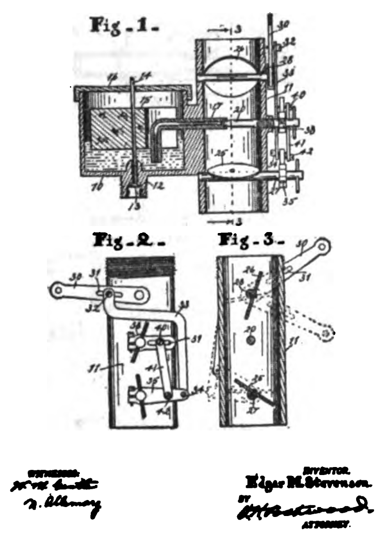
SPRAY CARBURETER.



E. M. STEVENSON.

CARBURETER.

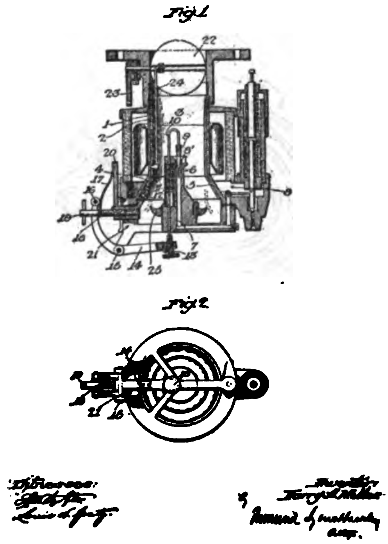
910,396. Patented Jan. 19, 1909.

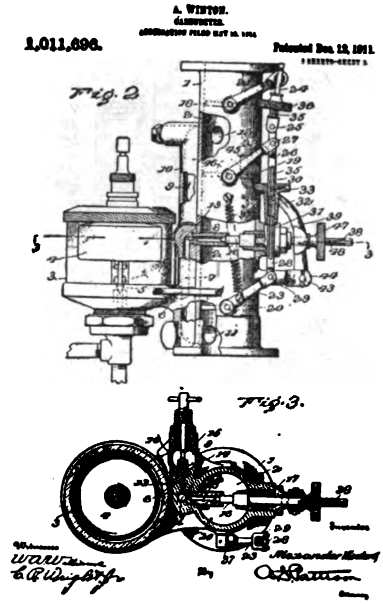


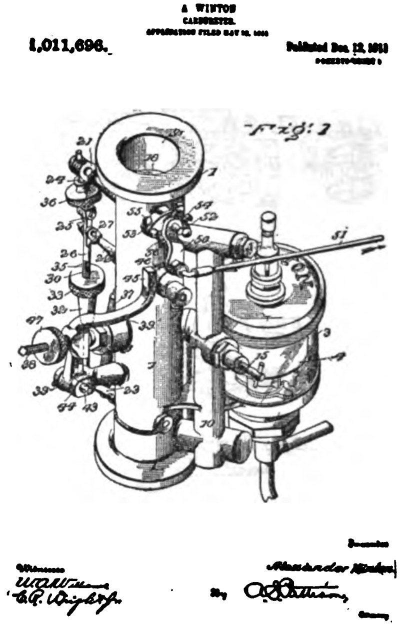
H. A. MILLER.

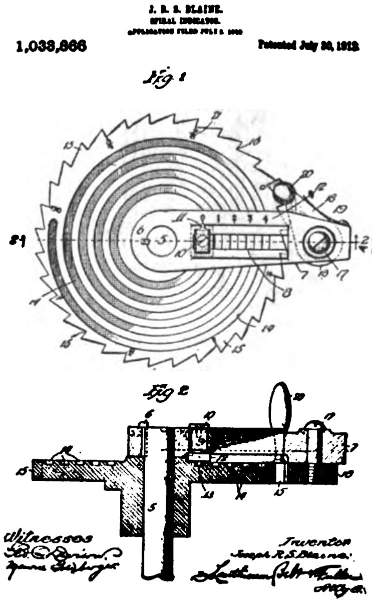
CARBURETER.

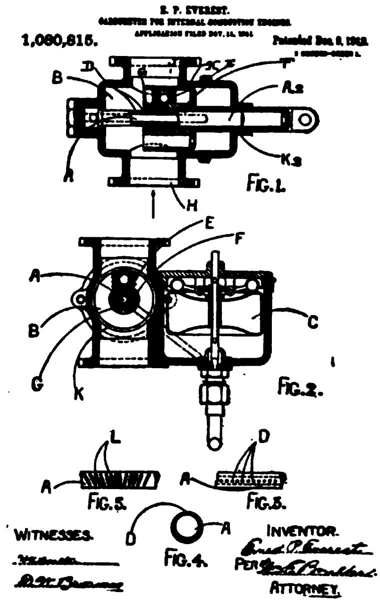
983,947. Patented Jan. 31, 1911.




A. WINTON.
CARBURETER.
1,011,696.
Patented Dec. 12, 1911.
Fig. 2
Fig. 3.

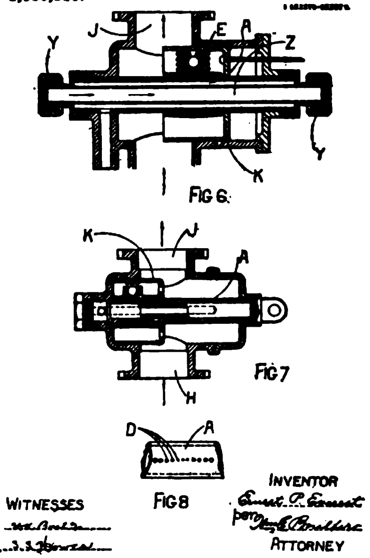

A. WINTON
CARBURETER.
1,011,696.
Patented Dec. 12, 1911
Fig. 1


J. R. S. BLAINE.
SPIRAL INDICATOR.
1,033,866
Patented July 30, 1912.
Fig 1
Fig 2
Witnesses
Inventor


E. P. EVEREST.
CARBURETER FOR INTERNAL COMBUSTION ENGINES.
1,060,815.
Patented May 6, 1913.
FIG. 1.
FIG. 2.
FIG. 3.
FIG. 5.
FIG. 4.
WITNESSES.
INVENTOR.
PER
ATTORNEY.

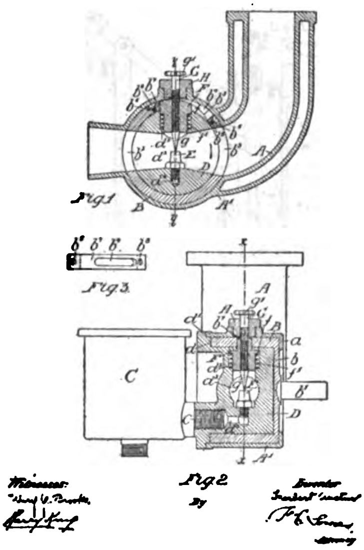
E. P. EVEREST.

1,080,815. Patented Dec. 9, 1913.



E. AUSTIN.

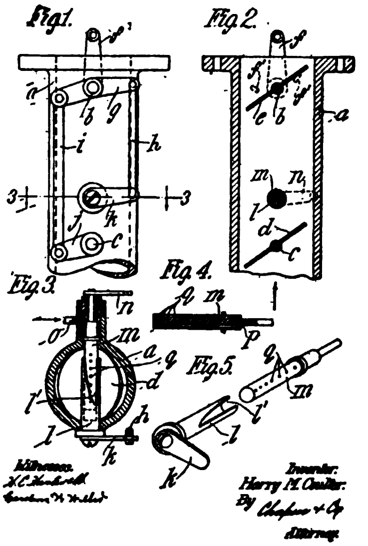
1,085,003. Patented Jan. 20, 1914.



H. M. COULTER.

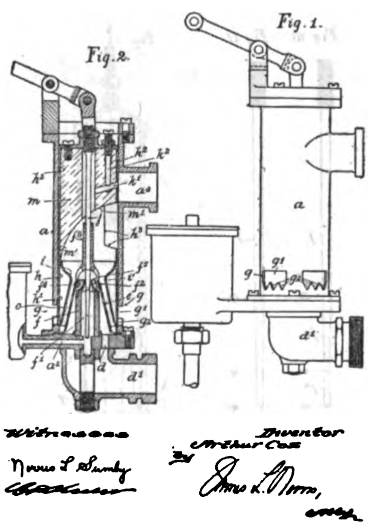
CARBURETER.

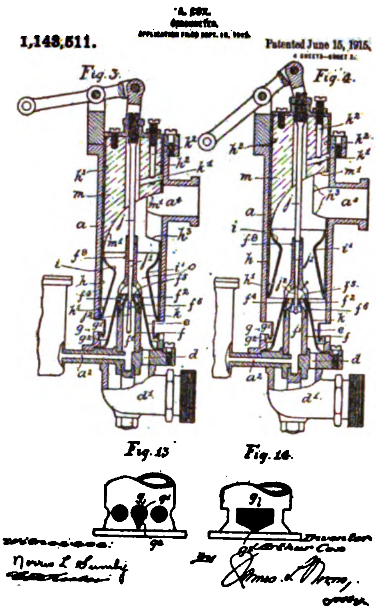
1,125,069. Patented Jan. 19, 1915.

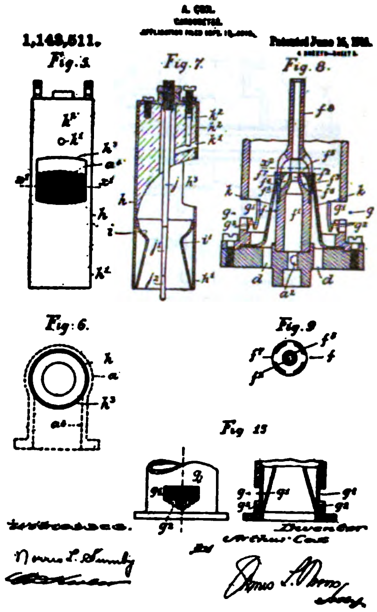


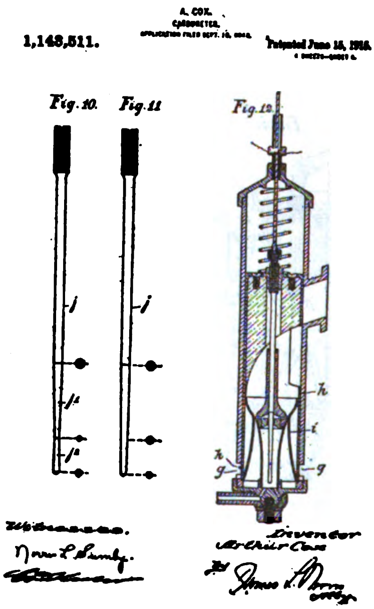
A. COX.

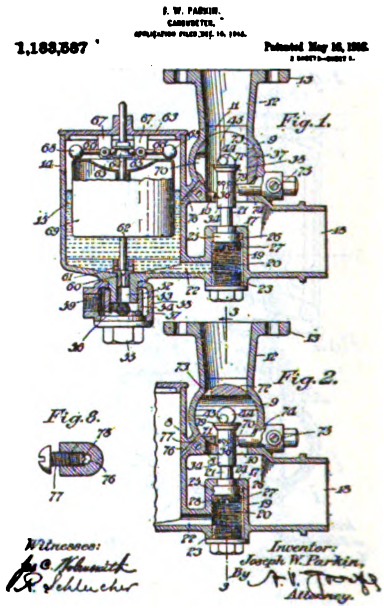
1,143,511. Patented June 15, 1915.




A. COX.
1,143,511.
Patented June 15, 1915.
Fig. 3.
Fig. 2.
Fig. 13
Fig. 14.
Inventor
Arthur Cox

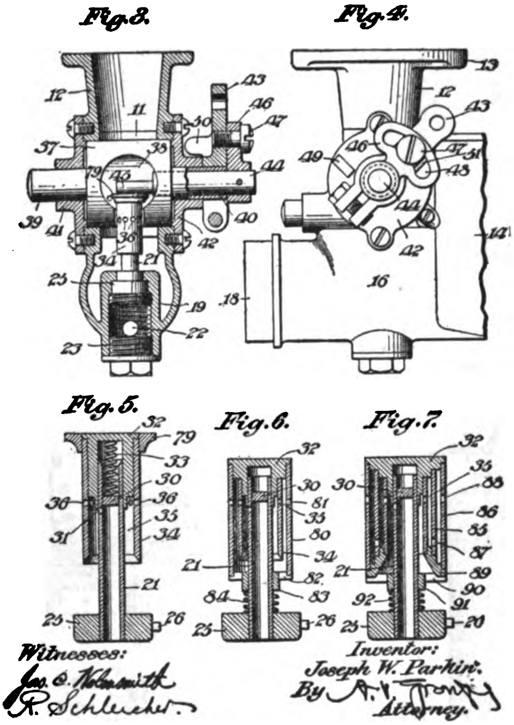

A. COX.
1,143,511.
Fig. 5.
Fig. 7.
Fig. 8.
Fig. 6.
Fig. 9
Fig. 15
Witnesses.
Inventor
Arthur Cox

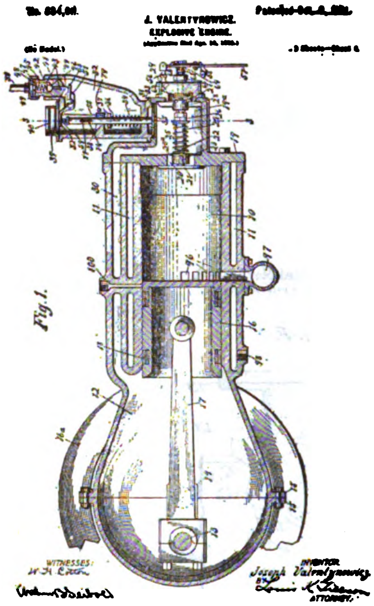

A. COX.
CARBURETER.
1,143,511.
Patented June 15, 1915.
Fig. 10.
Fig. 11
Fig. 12.
Witnesses.
Inventor
Arthur Cox

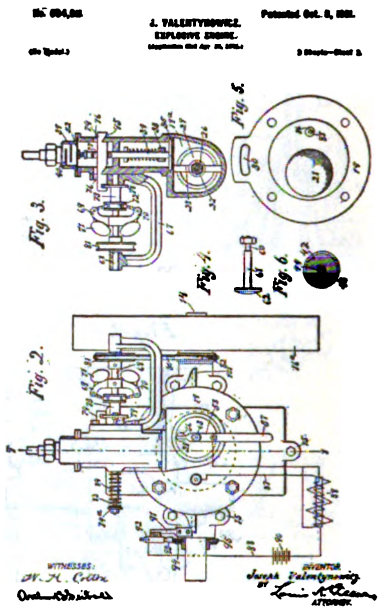

J. W. PARKIN.
CARBURETER.
1,183,587
Patented May 16, 1916.
Fig. 1.
Fig. 2.
Fig. 3.
Witnesses:
Inventor:
Joseph W. Parkin,
By
Attorney.

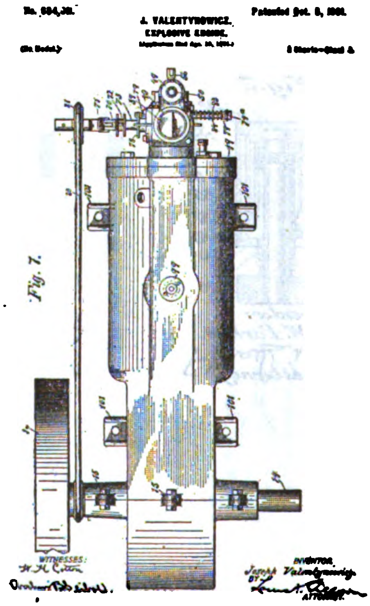
J. W. PARKIN.
CARBURETER.
APPLICATION FILED DEC. 16, 1914.

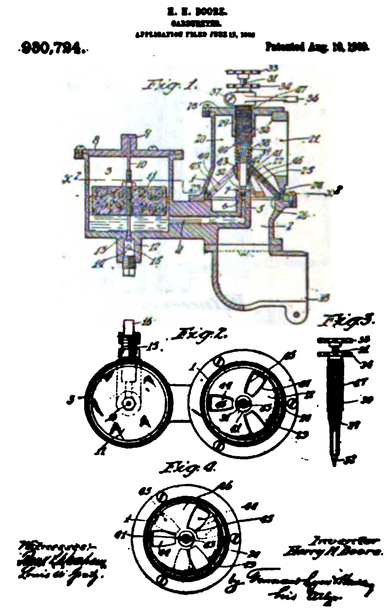
1,183,587. Patented May 16, 1916.
2 SHEETS—SHEET 2.



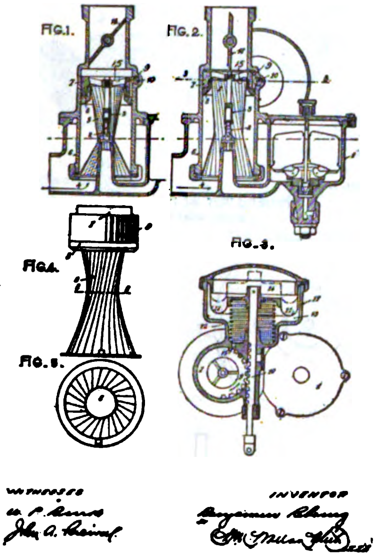

J. VALENTYNOWICZ.
EXPLOSIVE ENGINE.
Fig. 1.
WITNESSES:
INVENTOR
ATTORNEY.


J. VALENTYNOWICZ.
EXPLOSIVE ENGINE.
Fig. 2.
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 6.
WITNESSES:
INVENTOR
ATTORNEY.

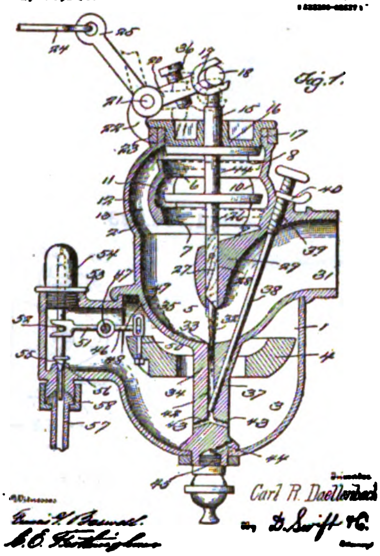

J. VALENTYNOWICZ.
EXPLOSIVE ENGINE.
Fig. 7.
WITNESSES:
INVENTOR.
ATTORNEY.


H. H. BOORE.
CARBURETER.
930,724.
Patented Aug. 10, 1909.
Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
Inventor
Harry H. Boore.

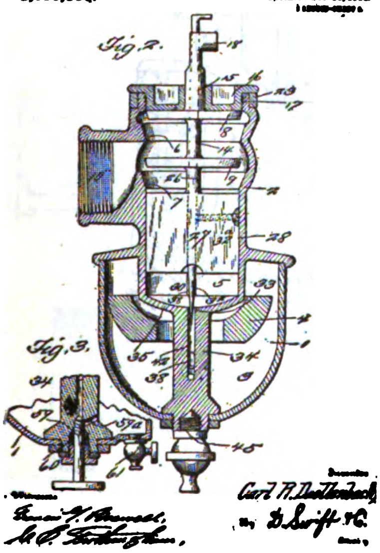
977,044. Patented Nov. 29, 1910.



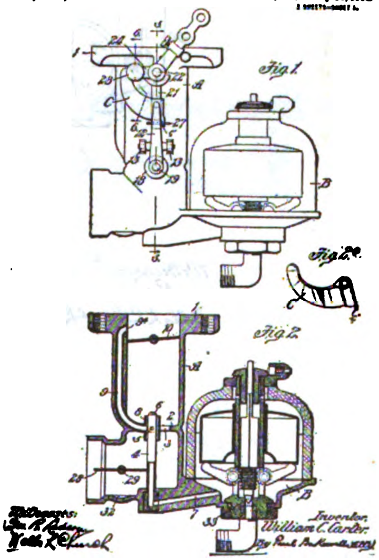
G. R. DAELLENBACH.
CARBURETER.
1,053,136. Patented Feb. 11, 1913.



G. R. DAELLENBACH.
CARBURETER.
1,053,136. Patented Feb. 11, 1913.



W. C. CARTER.
CARBURETER.
1,184,993. Patented May 30, 1916.



W. C. CARTER.

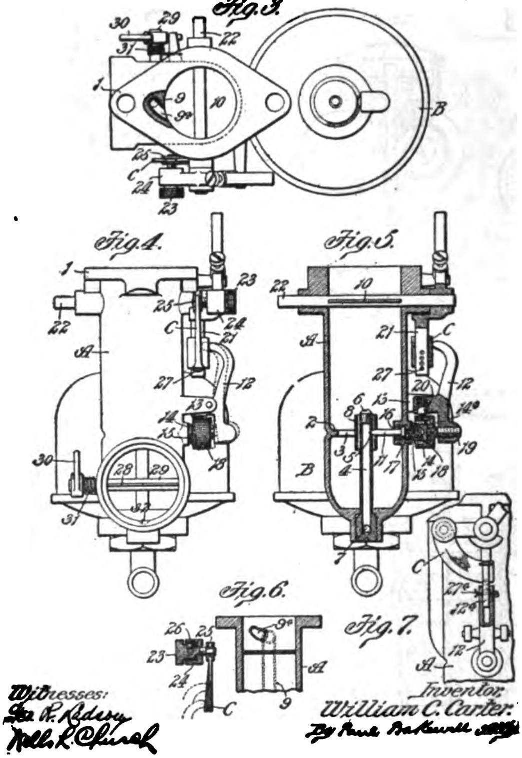
CARBURETER.

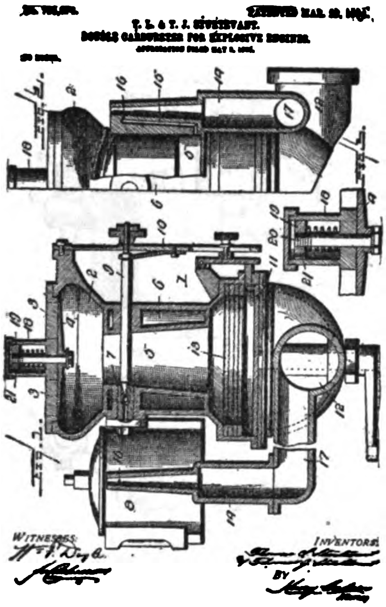
APPLICATION FILED APR. 24, 1911.

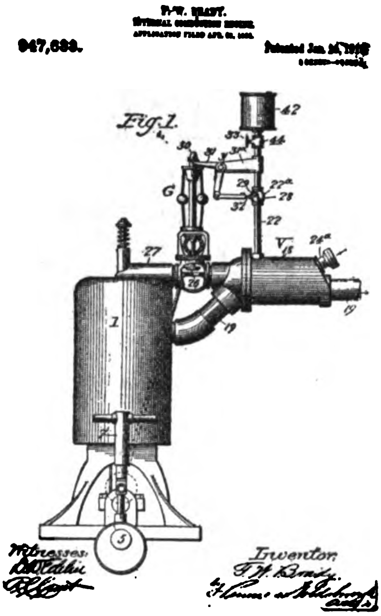
1,184,923.

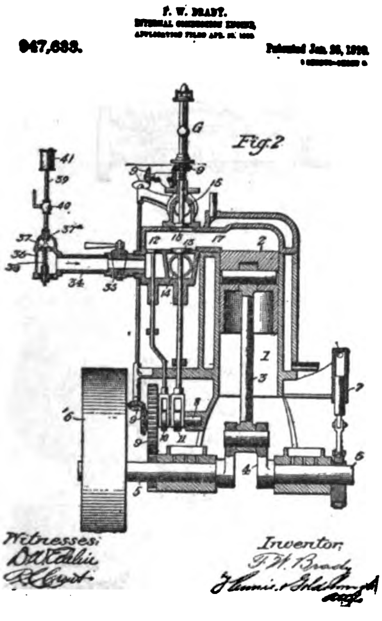
Patented May 30, 1916.

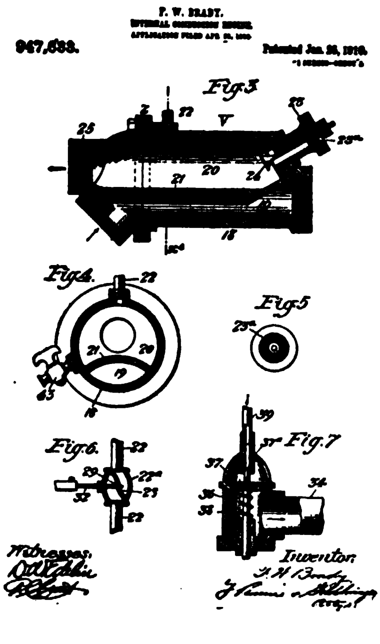
2 SHEETS—SHEET 2.




WITNESSES:
INVENTORS:
BY

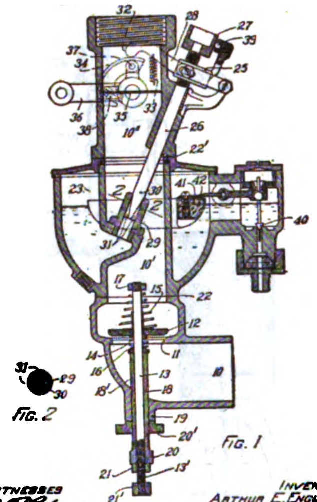

F. W. BRADY.
947,683.
Fig. 1.
Witnesses:
Inventor.
F. W. Brady


F. W. BRADY.
947,683.
Fig. 2
Witnesses:
Inventor.
F. W. Brady


F. W. BRADY.
947,683.
Fig. 3
Fig. 4.
Fig. 5
Fig. 6.
Fig. 7
Witnesses:
Inventor.

A. E. ENGLAND.

961,590. Patented June 14, 1910.

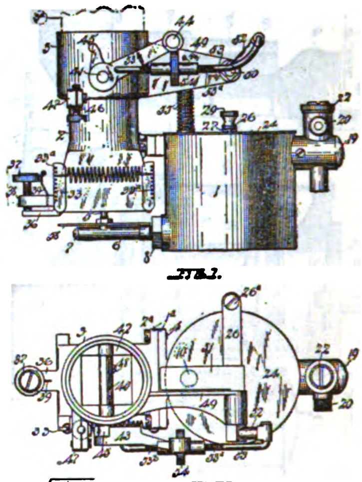


WITNESSES

INVENTOR
ARTHUR E. ENGLAND
BY HIS ATTORNEY

J. HARRIS.

1,066,606. Patented July 8, 1913.

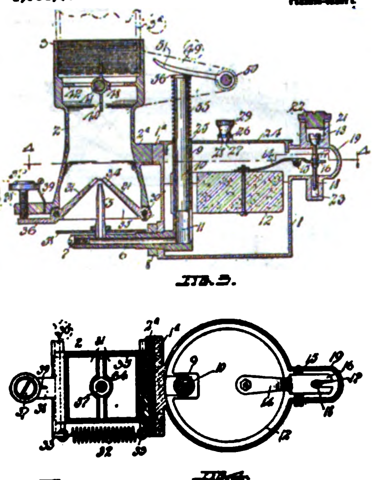


Witnesses:

Inventor
By
Attorney

J. HARRIS.

1,066,606. Patented July 8, 1913.

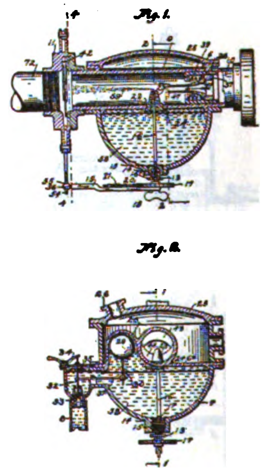


Witnesses:

Inventor
By
Attorney

L. SLIGER.

Reissued Dec. 1, 1914. 13,887.

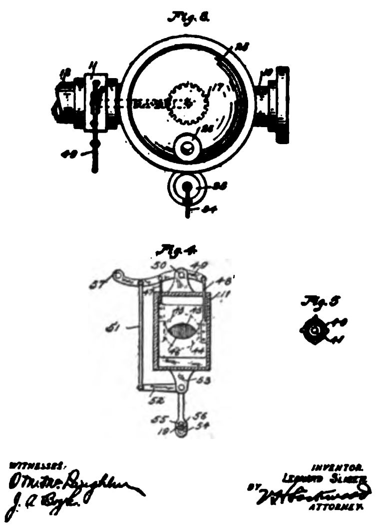


WITNESSES:

INVENTOR
BY
ATTORNEY

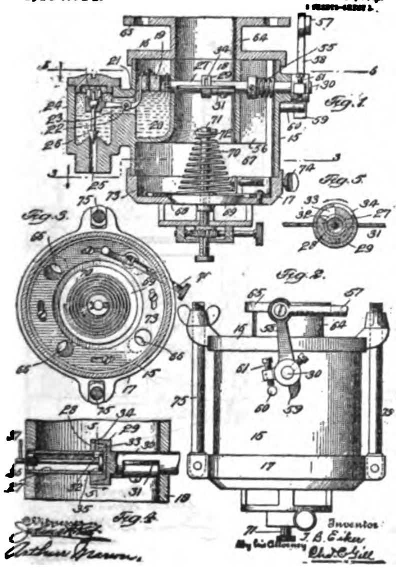
L. SIGER.
CARBURETER.
APPLICATION FILED APR. 22, 1914.

Reissued Dec. 1, 1914. 13,827.
2 SHEETS—SHEET 2.



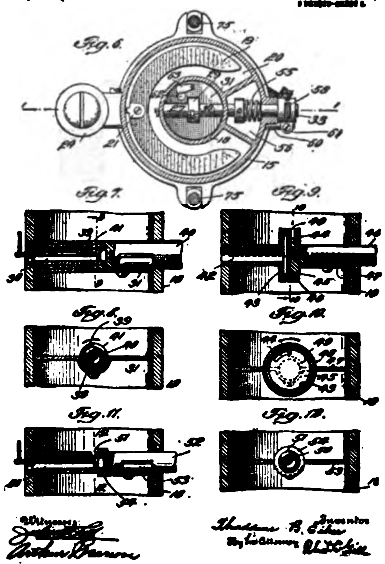
T. B. SIKES.
CARBURETER.
APPLICATION FILED FEB. 1, 1913.

1,132,814. Patented Mar. 16, 1915.
2 SHEETS—SHEET 1.

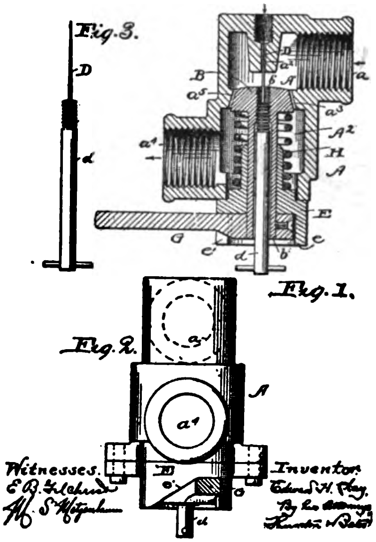


T. B. SIKES.
CARBURETER.
APPLICATION FILED FEB. 1, 1913.

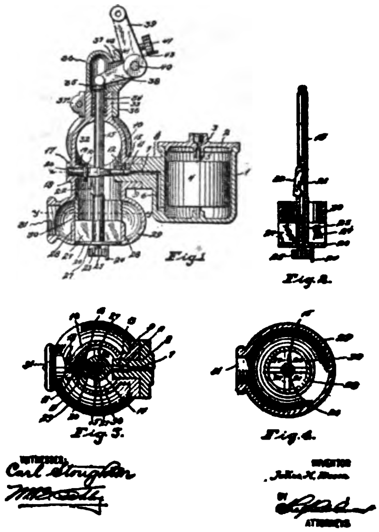
1,132,814. Patented Mar. 16, 1915.
2 SHEETS—SHEET 2.



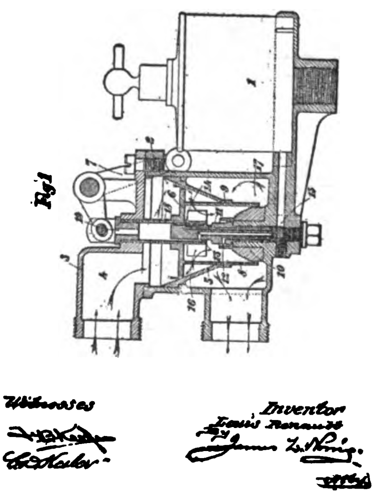
No. [illegible] PATENTED SEPT. [illegible], 190[illegible].
E. H. CLAY.
CARBURETER FOR EXPLOSIVE ENGINES.
APPLICATION FILED JUNE [illegible].
NO MODEL.



No. [illegible] PATENTED [illegible]
J. H. MASON.
CARBURETER.
APPLICATION FILED MAR. [illegible]

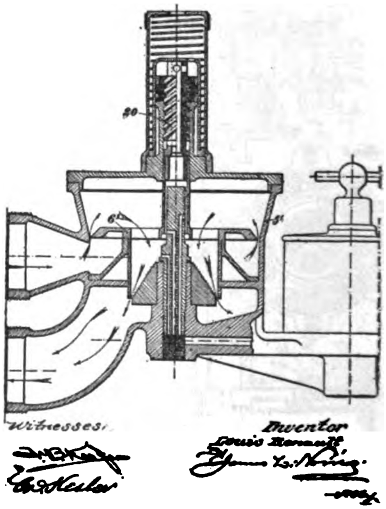


No. [illegible] PATENTED APR. 24, 1906.
L. RENAULT.
CARBURETER.
APPLICATION FILED MAY [illegible].
[illegible] SHEETS—SHEET [illegible].



No. [illegible] PATENTED APR. 24, 1906.
L. RENAULT.
CARBURETER.
APPLICATION FILED MAY [illegible].
[illegible] SHEETS—SHEET [illegible].

Fig. 2



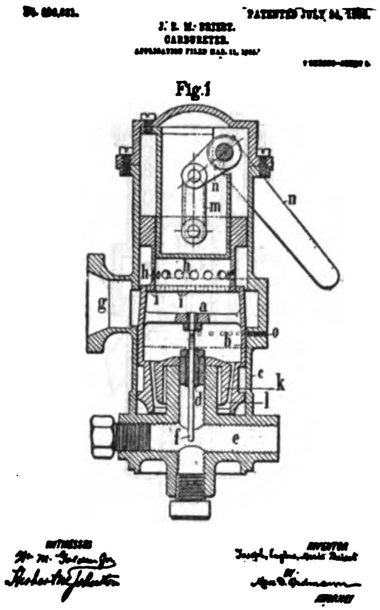


Fig.1
n
m
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a
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c
k
l
d
f
e
WITNESSES
INVENTOR
ATTORNEY

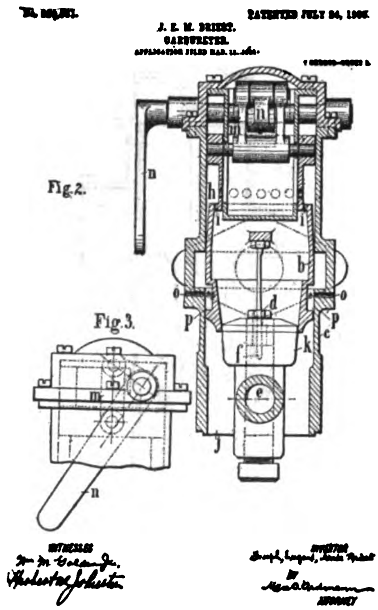
Fig.2.
Fig.3.
n
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p
c
k
f
e
j
WITNESSES
INVENTOR
ATTORNEY

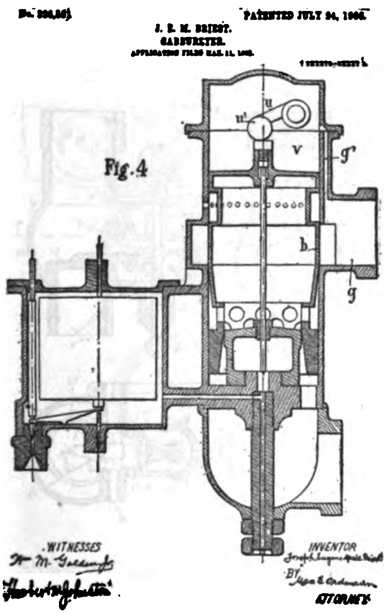
Fig.4
u
u'
v
g'
b
g
WITNESSES
INVENTOR
ATTORNEY

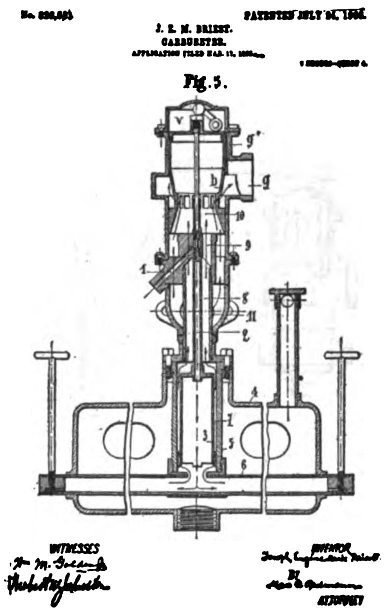
Fig.5.
v
g'
b
g
10
9
4
8
11
2
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3
5
6
WITNESSES
INVENTOR
ATTORNEY

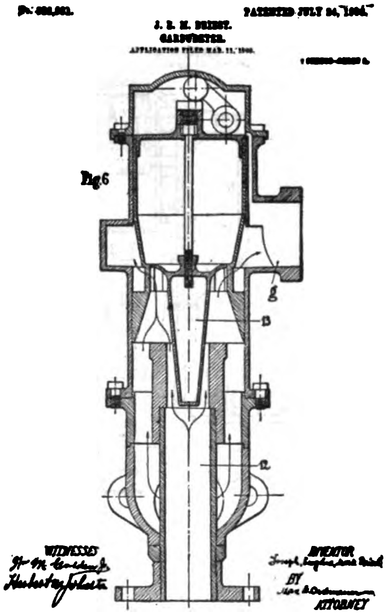


Fig. 6

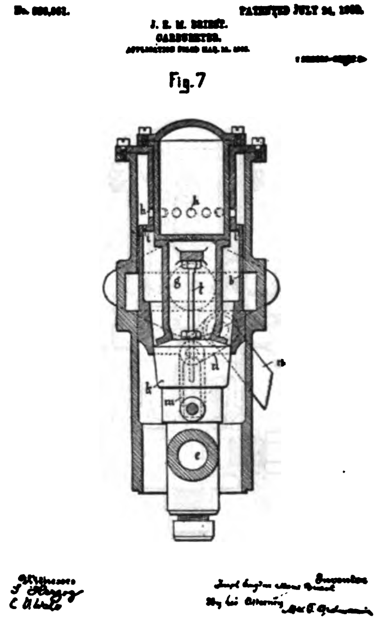


Fig. 7

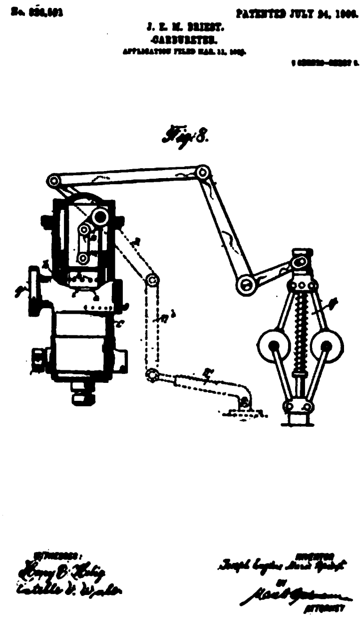
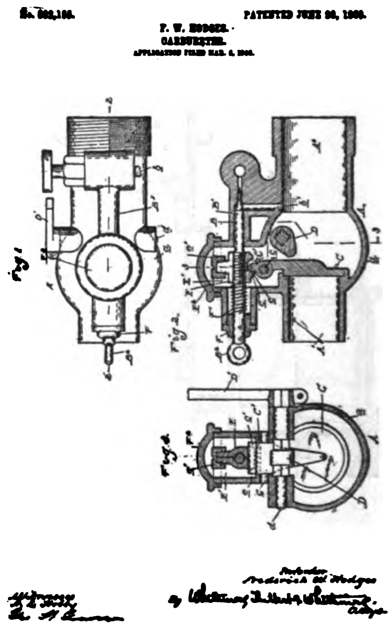
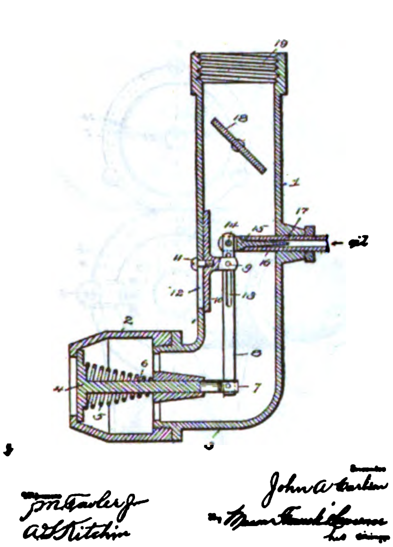


Fig. 8.

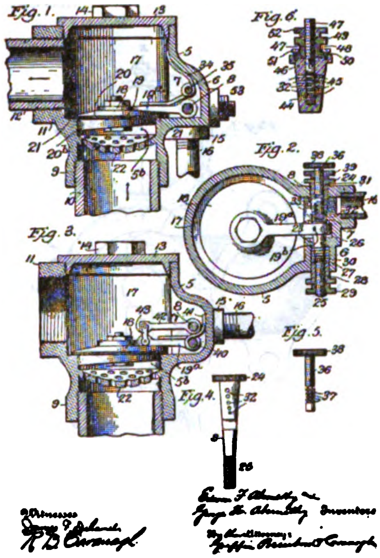


J. A. CARLSON.
CARBURETER.

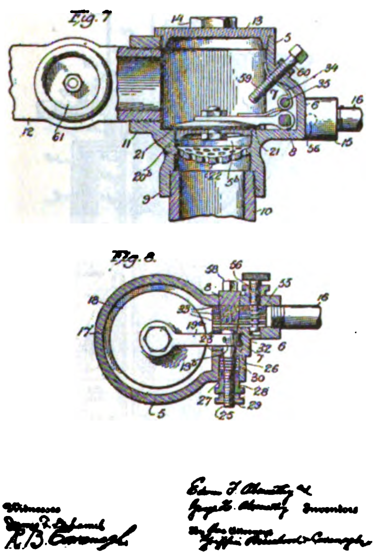
Patented July 6, 1909.



PATENTED AUG. 11, 1908.
E. F. & G. H. ABERNETHY.
CARBURETER FOR HYDROCARBON ENGINES.

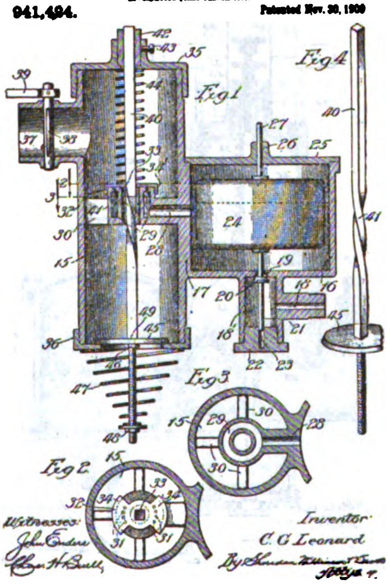


PATENTED AUG. 11, 1908.
E. F. & G. H. ABERNETHY.
CARBURETER FOR HYDROCARBON ENGINES.



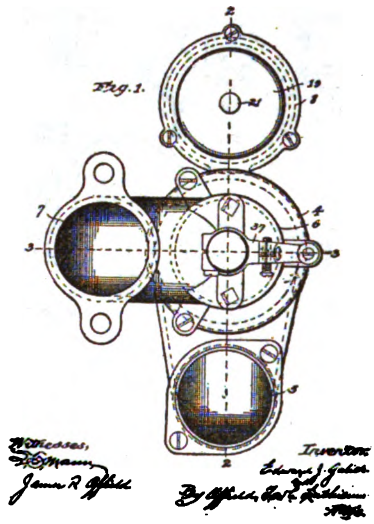
C. G. LEONARD.
CARBURETER.

941,494. Patented Nov. 30, 1909.



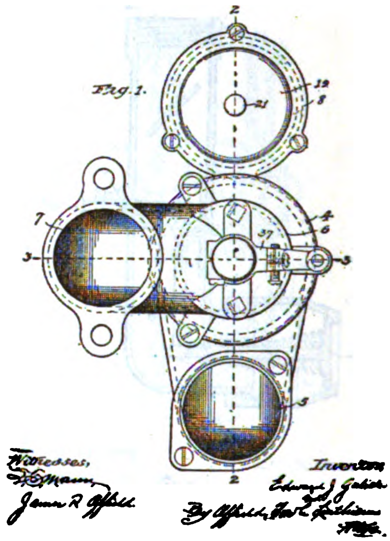
E. J. GULICK.
CARBURETER.
APPLICATION FILED MAY 4, 1908.

971,036. Patented Sept. 27, 1910.



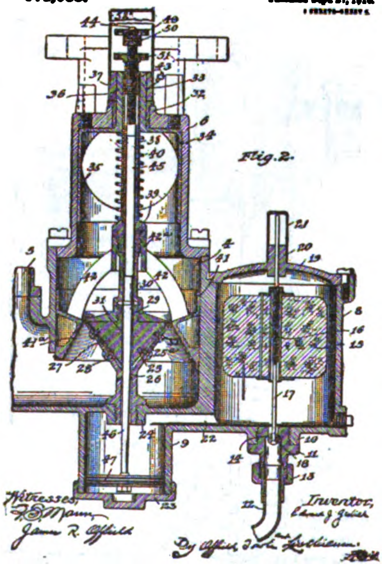
E. J. GULICK.
CARBURETER.
APPLICATION FILED MAY 4, 1908.

971,036. Patented Sept. 27, 1910.



E. J. GULICK.
CARBURETER.
APPLICATION FILED MAY 4, 1908.

971,036. Patented Sept. 27, 1910.



E. J. GULICK.
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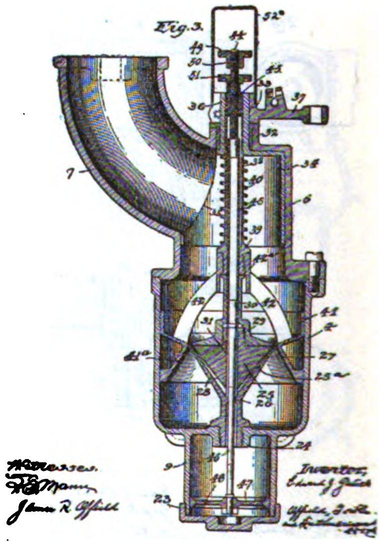
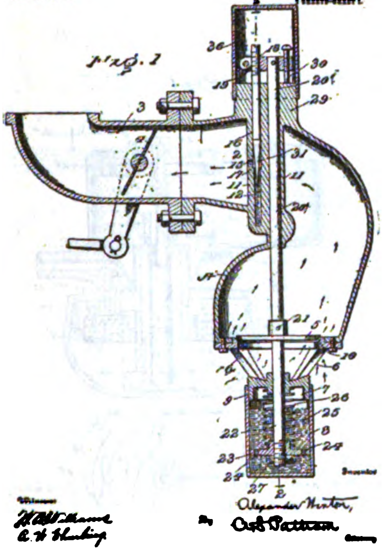
APPLICATION FILED MAY 4, 1908.

971,036. Patented Sept. 27, 1910.



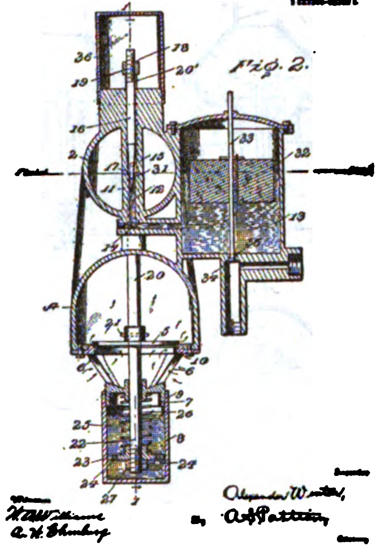
A. WINTON.
CARBURETER.
APPLICATION FILED [illegible]

984,874. Patented Feb. 21, 1911.



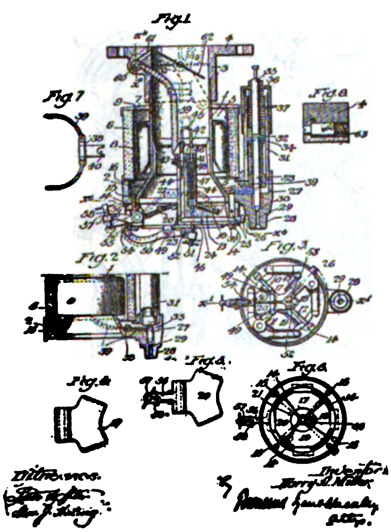
A. WINTON.
CARBURETER.
APPLICATION FILED [illegible]

984,874. Patented Feb. 21, 1911.



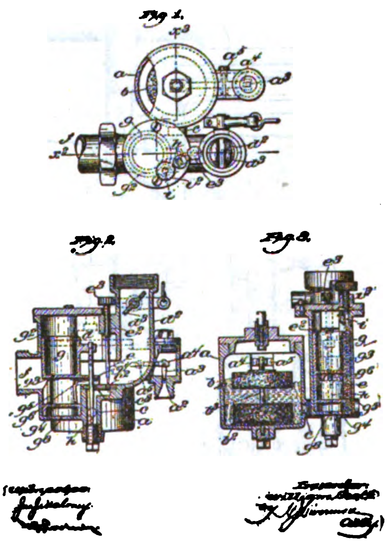
E. A. MILLER.
CARBURETER.
APPLICATION FILED [illegible]

996,093. Patented June 20, 1911.



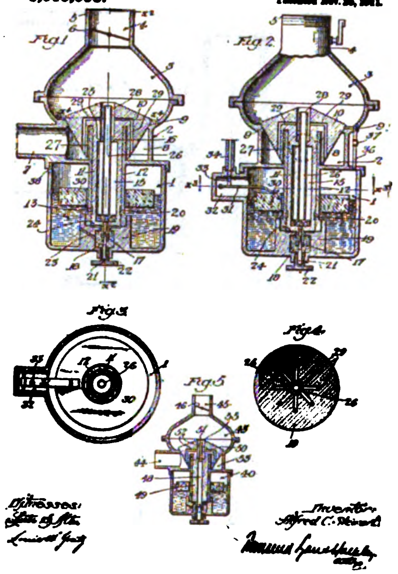
W. SCOTT.
CARBURETER.
APPLICATION FILED [illegible]

1,006,411. Patented Oct. 17, 1911.



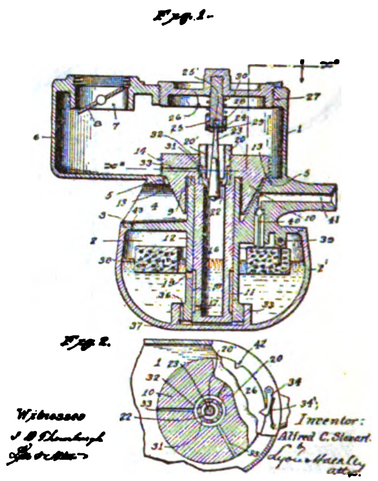
A. C. STEWART.
CARBURETER.

1,010,008. Patented Nov. 28, 1911.



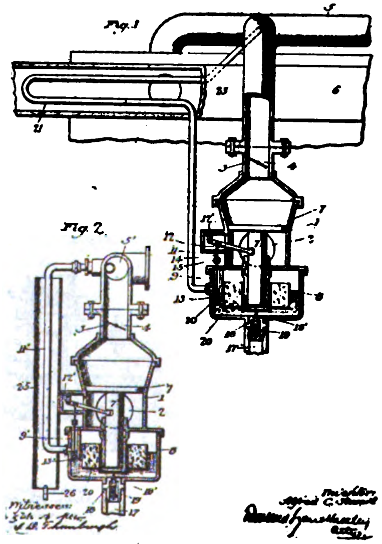
A. C. STEWART.
CARBURETER.

1,039,307. Patented July 9, 1912.



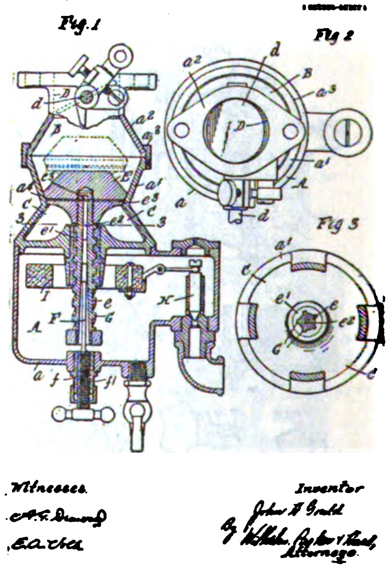
A. C. STEWART.
CARBURETER.

1,049,417. Patented Jan. 7, 1913.



J. E. GOULD.
CARBURETER.

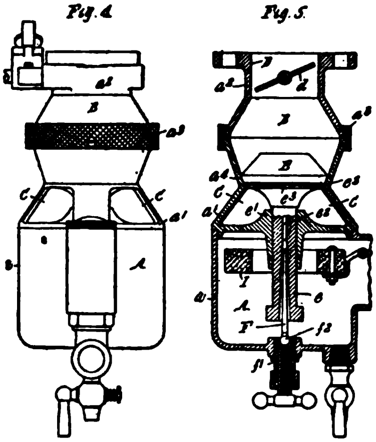
1,050,059. Patented Jan. 7, 1913.



J. H. GOULD.
CARBURETER.

1,050,059. Patented Jan. 7, 1913.

Fig. 4 Fig. 5

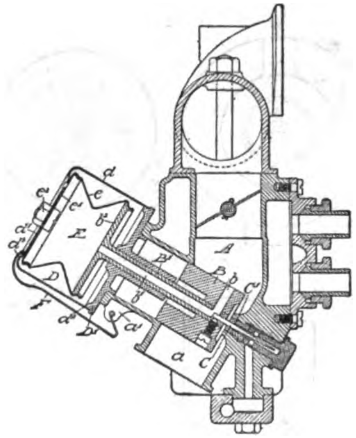


Witnesses

Inventor
John H. Gould,
Attorneys

M. R. LAWRENCE.
CARBURETER FOR INTERNAL COMBUSTION ENGINES.

1,088,331. Patented Feb. 24, 1914.

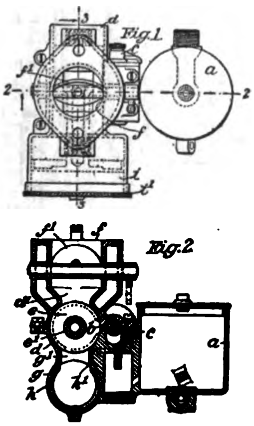


Witnesses:

Inventor:

W. E. MARTIN.
CARBURETER.
APPLICATION FILED APR. 17, 1914.

1,115,951. Patented Nov. 3, 1914.

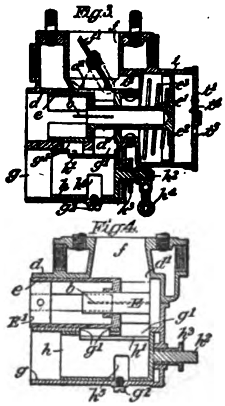


Witnesses

Inventor
William E. Martin

W. E. MARTIN.
CARBURETER.
APPLICATION FILED APR. 17, 1914.

1,115,951. Patented Nov. 3, 1914.

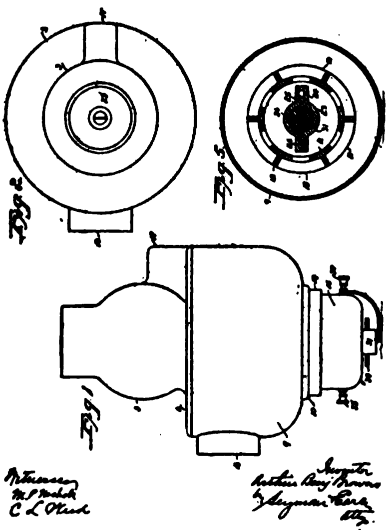


Witnesses

Inventor
William E. Martin

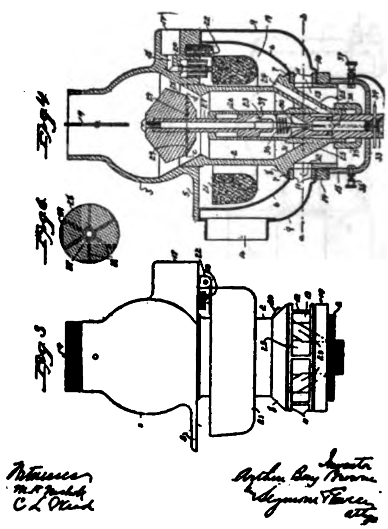
A. B. BROWNE.
CARBURETER.
APPLICATION FILED JAN. 14, 1914.

1,120,198. Patented Dec. 8, 1914.
3 SHEETS—SHEET 1.



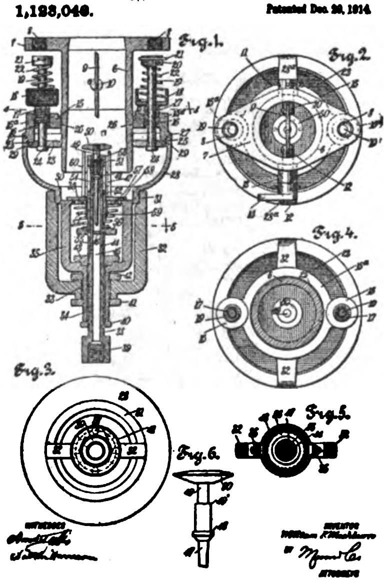
A. B. BROWNE.
CARBURETER.
APPLICATION FILED JAN. 14, 1914.

1,120,198. Patented Dec. 8, 1914.
3 SHEETS—SHEET 2.



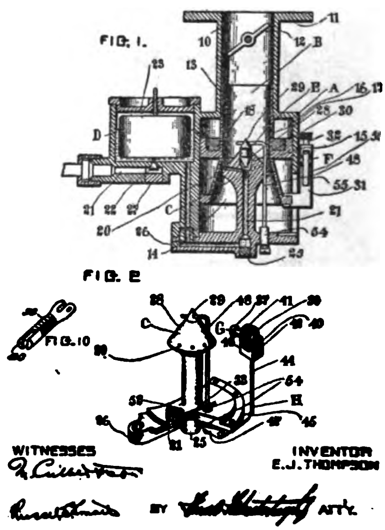
W. F. WASHBURN.
CARBURETER.
APPLICATION FILED OCT 16, 1911.

1,123,046. Patented Dec. 29, 1914.



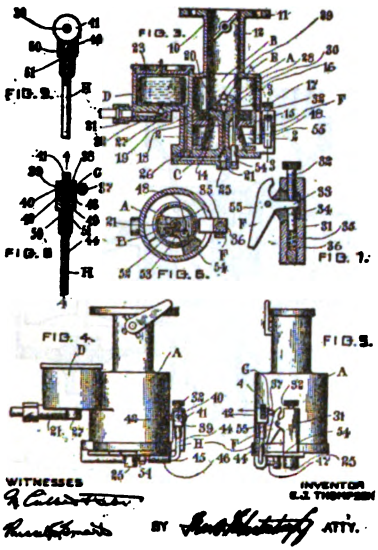
E. J. THOMPSON.
CARBURETER.
APPLICATION FILED JUNE 24, 1913.

1,130,850. Patented Mar. 2, 1915.
2 SHEETS—SHEET 1.



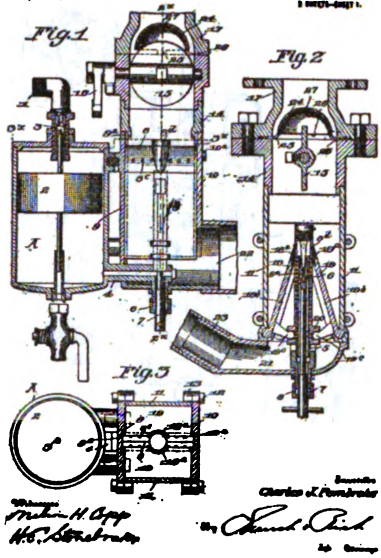
E. J. THOMPSON.
CARBURETER.

1,130,850. Patented Mar. 9, 1915.



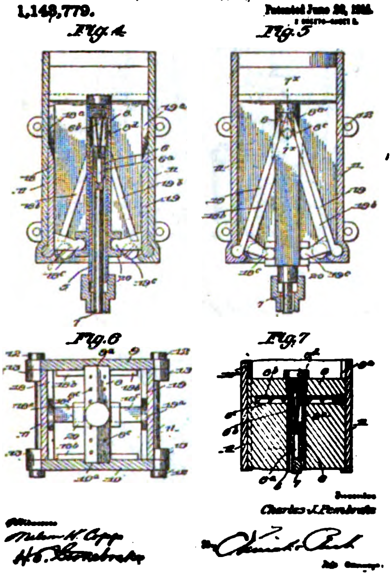
C. J. PEMBROKE.
CARBURETER.

1,143,779. Patented June 22, 1915.



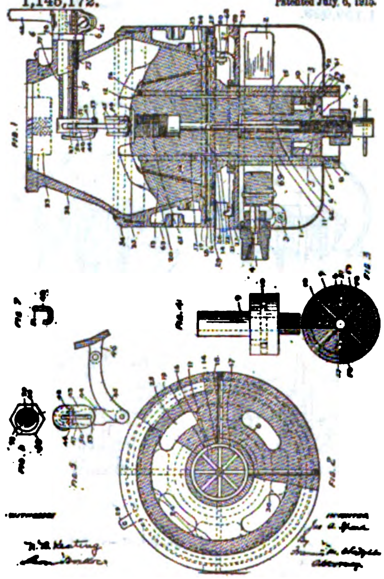
C. J. PEMBROKE.
CARBURETER.

1,143,779. Patented June 22, 1915.



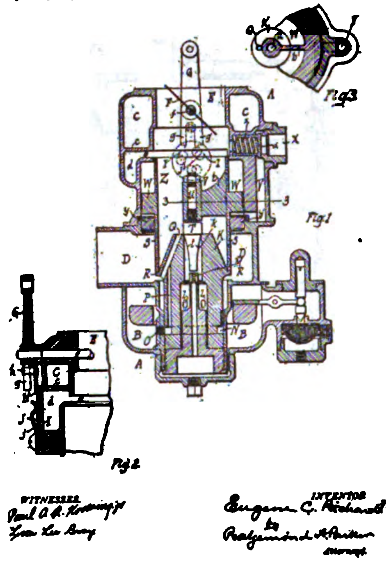
J. A. SPEER.
CARBURETER.

1,145,172. Patented July 6, 1915.



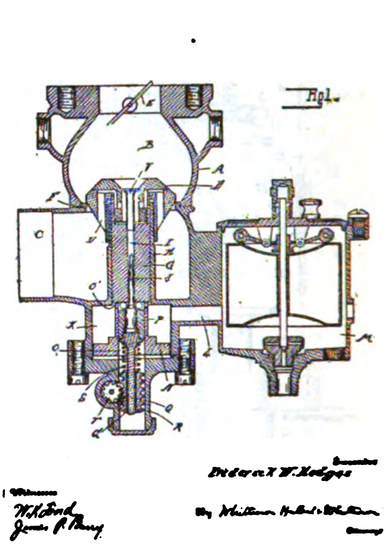
E. C. RICHARD.
CARBURETER.
APPLICATION FILED FEB. 15, 1912.

1,149,291. Patented Aug. 10, 1915.



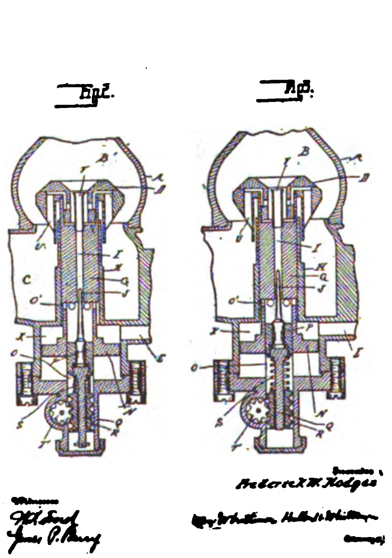
F. W. HODGES.
CARBURETER.

1,159,099. Patented Nov. 2, 1915.



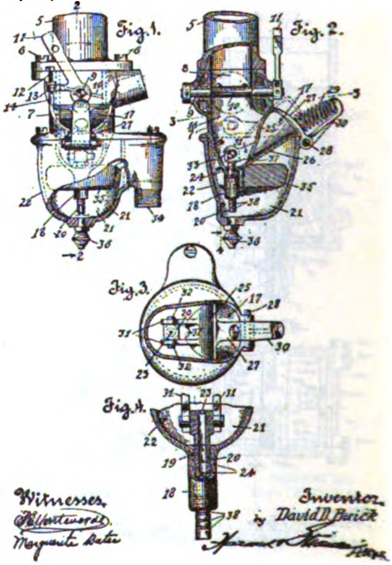
F. W. HODGES.
CARBURETER.

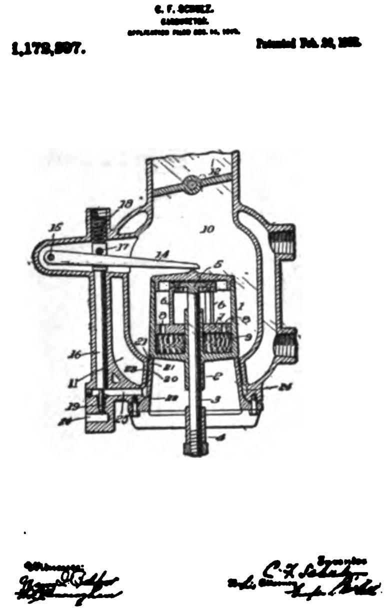
1,159,099. Patented Nov. 2, 1915.

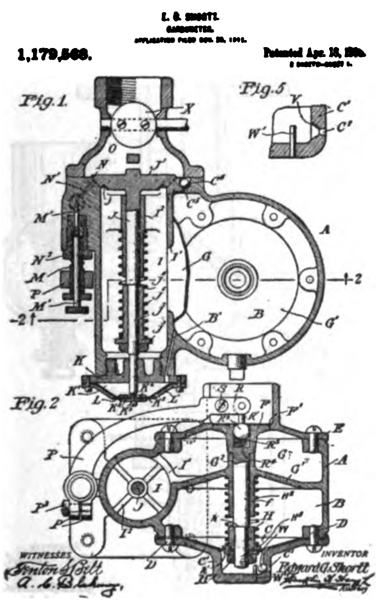


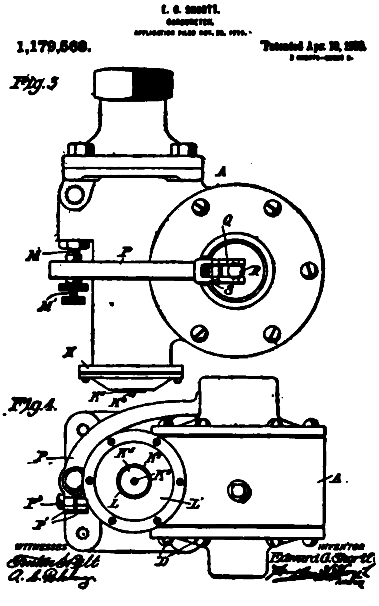
D. D. BUICK.
CARBURETER.

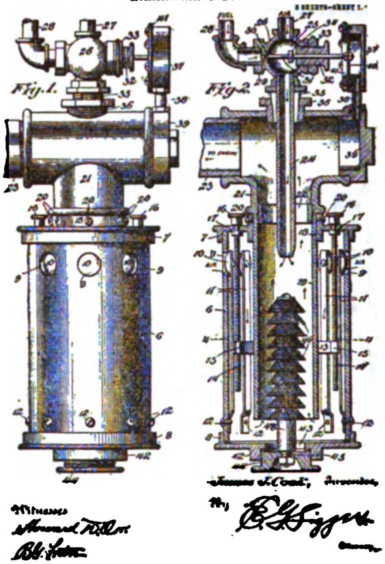
1,162,680. Patented Nov. 30, 1915.

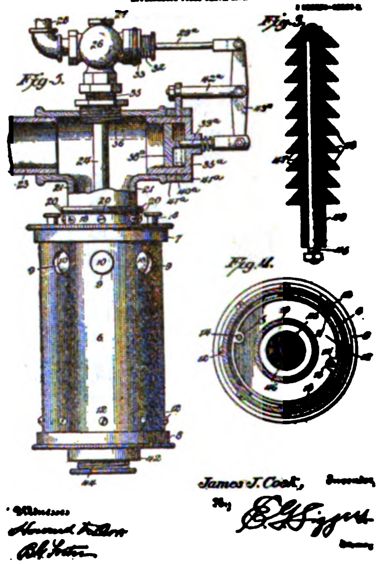



1,172,897.
Patented

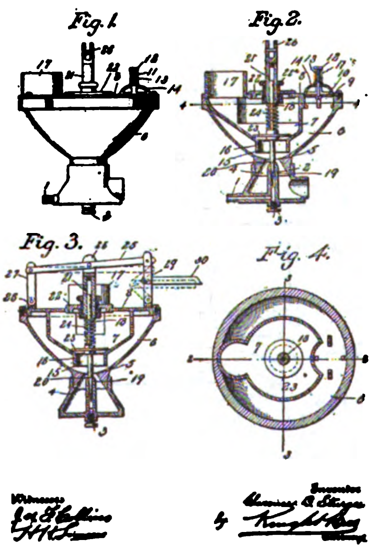

1,179,568.
Patented
Fig. 1.
Fig. 5
Fig. 2
WITNESSES
INVENTOR
Edward G. Shortt


1,179,568.
Patented
Fig. 3
Fig. 4.
WITNESSES
INVENTOR
Edward G. Shortt

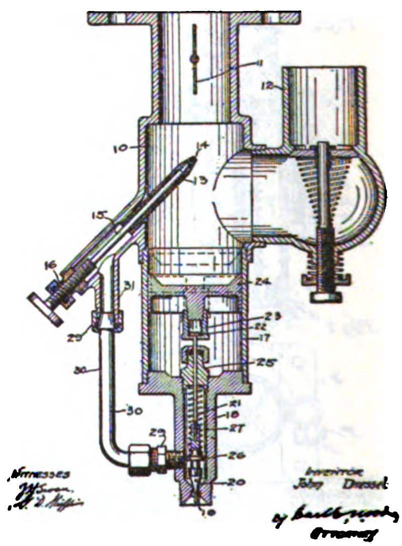




918,607.

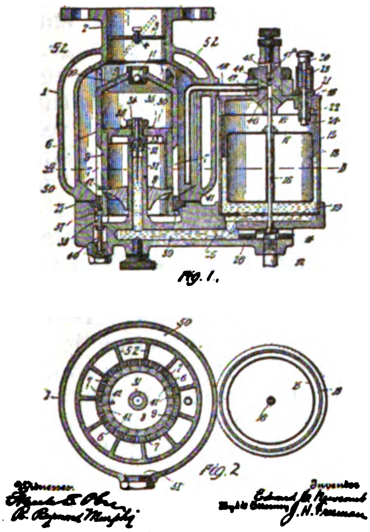


1,196,150.



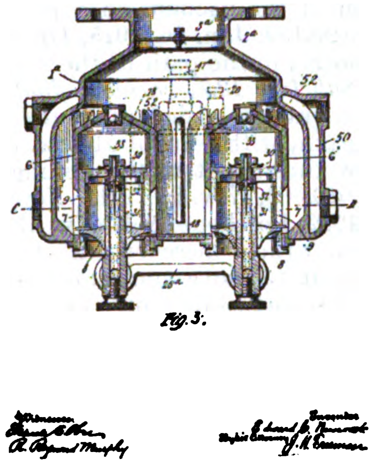
E. C. NEWCOMB.
CARBURETER.

1,010,066. Patented Nov. 28, 1911.



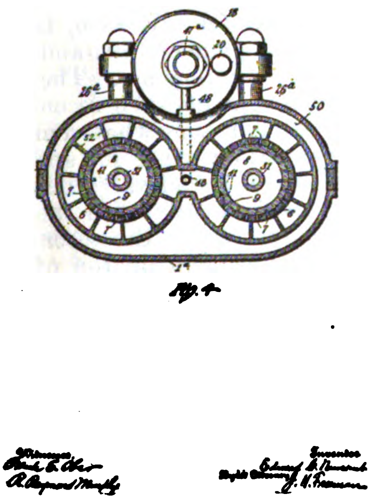
E. C. NEWCOMB.
CARBURETER.

1,010,066. Patented Nov. 28, 1911.



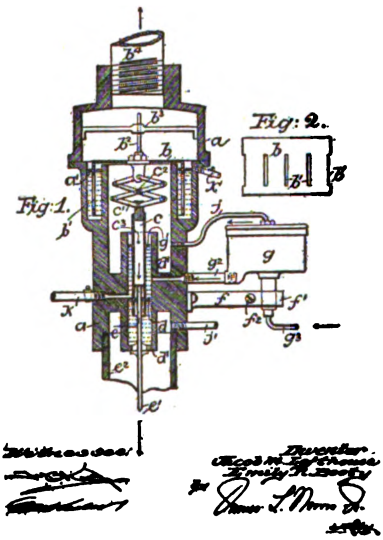
E. C. NEWCOMB.
CARBURETER.

1,010,066. Patented Nov. 28, 1911.



J. M. LOFTHOUSE & E. R. BOOTY.
CARBURETER.

1,025,316. Patented May 7, 1912.



Subclass 12.6—Valved fuel inlet between air inlet valve and throttle, fuel valve controlled independently by vacuum or air flow.—On page 402 (838,085, Dec. 11, 1906, Cook) the fuel valve is operated by a diaphragm, while the air enters a series of spring check valves. The flow itself lifts the flow disk and controls the lift of the metering pin, on page 402 (918,607, Apr. 20, 1909, Sturges), air entering through a fixed primary and an automatic secondary passage. Action of the vacuum on a piston moves the fuel valve on page 402 (1,126,159, Jan. 26, 1915, Dressel), the fuel entering the air through a nozzle in the path of the stream from an automatic air valve.

Subclass 12.7, variable float chamber pressure.—The combination of a gravity loaded automatic air valve actuating a long fuel metering pin, with control of float chamber pressure by an adjustable air flow through it to the mixing chamber, is illustrated on page 403. (1,010,066, Nov. 28, 1911, Newcomb.) On page 403 (1,025,816, May 7, 1912, Lofthouse & Booty) there is shown an air inlet of gas holder form with a mercury seal, the side walls having slots. Associated with it to move simultaneously in the opposite direction is a fuel tube sealed also in mercury and with fuel floating on the top. The fuel escapes by gravity through a hole at whatever depth beneath the surface may be fixed by the air bell. The fuel then rises with the air. The float chamber pressure is equalized, so the fuel flow will be purely by gravity head.

Class 13—Carburetors, proportioning flow aspirating, single fuel and multiple air inlets, both with regulating valves.—This is practically a modification of the common auxiliary air valve class by adding to it a fuel valve, the action of which is expected to connect and compensate for the deficiencies of the same combination without the fuel valve and indicates a failure to accept the fixed fuel inlet with its air-valve compensators as adequate.

Part of the air enters through an automatic valve leading to a throttle-controlled port on page 409 (813,653, Feb. 27, 1906, Law), part enters directly through one fixed inlet as primary air, and still another part through another fixed inlet as secondary air. The fuel valve is controlled by the throttle that also controls such secondary air as first enters through an automatic valve, a somewhat complex combination. Also unusual is the arrangement on pages 409 and 410 (817,903, Apr. 17, 1906, Comstock), in which the fuel valve delivering fuel to the primary air is controlled mechanically with the secondary air, the primary air carrying the fuel meets the secondary diluting air at a distance where the two pipes join on top of the engine. One of the stationary-engine schemes is illustrated on page 410 (876,519, Jan. 14, 1908, Brothers), having a fixed primary air inlet and a secondary air swing valve linked to a threaded fuel needle valve, both being under governor control. It is difficult to see how such an arrangement in the absence of a throttle could maintain any definite proportionality, because as needle and secondary air valves close, the vacuum on the primary air inlet must increase and its flow as well.

A fixed primary air inlet and automatic secondary are associated with a fuel valve that lifts directly with the vacuum acting on a piston at its top on page 412. (1,132,934, Mar. 23, 1915, Heitger.) Another power-driven-fan case, this time falling in the class of single variable fuel and multiple variable air inlets, is shown on page 410. (1,154,530, Sept. 21, 1915, Merriam & York.) The fuel

needle valve, located in a fixed primary air Venturi throat, is regulated by the speed of a fly-ball governor, which also adjusts simultaneously the secondary air. The mixture enters the fan casing at its center and is discharged at a pressure in excess of atmosphere, but proportionality will evidently vary with the engine inlet header pressure, which is the fan back pressure whenever flow changes without a speed change. The torque produced by the air striking the curved vanes of what would be an air turbine, were it free to rotate, causes it to turn slightly on its screw-threaded stem, thereby controlling a fuel valve, on page 412. (1,158,324, Oct. 26, 1915, Smith.) An automatic secondary air valve is provided.

A fixed primary with an automatic secondary air inlet combination has a fuel valve that opens by turning in its threaded casing, the turning being caused by the rise of a flow disk in the mixture path, which rotates as it rises because of a helical rib engaging a notch on its edge, the fuel valve stem being square is turned thereby. This is shown on page 412. (1,178,064, Apr. 4, 1916. Fahrney.)

Subclass 13.1—valved fuel inlet, fixed primary air, fixed or primary secondary air inlets, throttle control of fuel inlet valve.—Fixed primary air passes upward around the regulating fuel valve and meets secondary air entering through a tapered slot in the side of the cylindrical sleeve throttle is on page 411. (886,265, Apr. 28, 1908, Speed.) A yoke from the throttle stem actuates a sliding cam and roller gear for moving the fuel valve. Rotation of a barrel sleeve throttle surrounding the fuel inlet and a cross tube for primary air controls the secondary air by a port opposite to the throttle port and lifts the fuel needle by an inclined cam surface rotated under a lever attached to it in the form on page 411. (950,423, Feb. 22, 1910, Anderson.) Two fuel inlets, one fixed and the other varying, are similarly located and act as one, the fixed serving only to insure the accuracy of the opening for idling, on pages 411 and 412. (976,258, Nov. 22, 1910, Gallagher.) The throttle controls fuel needle and the secondary air port. An example of a fuel needle placed at a distance from the fuel inlet nozzle is shown on page 413. (1,029,796, June 18, 1912, Dawson.) The nozzle is located in a fixed primary air inlet, and the throttle controls a pair of secondary air ports and the fuel needle valve. Location of the regulating needle valve in a tapered air throat associated with a secondary sliding air sleeve beyond it, both sleeve and needle being operated by linkage from a damper throttle is illustrated on pages 413 and 414. (1,065,462, June 24, 1913, Miller.) A comparatively recent form of the rotating barrel sleeve acting as both throttle and secondary air valves at opposite ports, and carrying a fixed primary air inlet along the axis, the fuel needle valve cam operated by the rotation, is shown on page 414. (1,125,339, Jan. 19, 1915, Keizer.) Here the primary air throat lies wholly within the barrel and is provided with a bend or side outlet shroud on top.

As an example of the effect of change of time in improving form, the same elements as were incorporated in figure 390 are again brought together in a new structure on pages 414 and 415 (1,148,485, July 27, 1915, Gallagher) about five years later. Attention is called to the substitution of a good form of tapered throat for the primary air instead of the former irregular one with no definite direction and making many eddy currents, the substitution of a damper for a longitudinal cylindrical throttle, a concentric for a side float chamber,

while retaining a linkage between the secondary air, the fuel needle and the throttle, and finally the separate low-speed fuel orifice.

Subclass 13.2—valved fuel inlet, valved primary and secondary air inlets, throttle control of both air inlets and the fuel inlet valve.—Again, the throttle is retained as the prime variable element of control, this time varying all areas with it, that of both of the air inlets and the fuel, on the old assumption that areas rather than pressures are the fundamental variables in proportionality maintenance as quantity varies, instead of giving due weight to both and using as the prime variable some unit that is a measure of flow.

On page 416 (1,134,366, Apr. 6, 1915, Barnes) a tapered throat is provided with a central tapered plug, serving as a primary air valve and sliding with the fuel needle on a fixed sleeve, and to it is connected a secondary air sleeve, and this triple-moving member acts as the throttle. The varying throat and fuel inlet relation itself acts as a compensation factor in this case. A rotating barrel sleeve acts similarly by controlling the outlets of both primary and secondary air passages, the same motion varying the fuel needle position on pages 416 and 417. (1,162,111, Nov. 30, 1915, Simpson.) The fuel inlet is here set in front of the air restriction so that it receives less vacuum than in the previous case.

Subclass 13.3—Valved fuel inlet, fixed primary, and throttle-controlled secondary air inlets, fuel valve controlled by the vacuum or air flow independently.—Making the variable air depend on the throttle and the fuel variation on the flow directly is a good example of mixed variables, because the two things that should vary together might naturally be expected to receive their motion from the same instead of different sources. Two examples only are given on page 418 (1,081,222, Dec. 9, 1913, Dürr), having again the double-ported rotating barrel to serve as secondary air and throttle valve. It is, however, screw threaded in its casing, so that it has a small axial motion with rotation. A spring-resisted piston within it carries the fuel valves and a fixed primary air passage passes through the end of the casing and through the piston rod to the central fuel opening. The fuel valve lifts an amount fixed by the spring tension and the vacuum, and thereby regulates the fuel delivered to the primary air, the amount of which is small. The old air impact flow disk is used to control the fuel in a chamber supplied with fixed primary and automatic secondary air arranged with an electric heater to operate on kerosene, as shown on page 418. (1,131,157, Mar. 9, 1915, Percival & Patterson.)

Subclass 13.4—Valved fuel inlets, fixed primary and automatic valved secondary air inlets, fuel valve controlled by the throttle.—As the use of the automatic secondary air valve in place of throttle control is a proper step, especially for the high capacity variable speed engine, it seems questionable that the throttle should be selected at the origin of fuel-valve regulation, but there are quite a number of cases of this sort.

A cam connection is provided between a damper throttle and the fuel needle on page 419 (870,052, Nov. 5, 1907, Schebler) and applied to a carburetor of the common fixed primary and automatic secondary air form. The fact that a fuel-valve adjustment is suggested at all for a carburetor of this large old class is a measure of lack of confidence in the adequacy of the compensation it affords

without the fuel valve. Another case of cam-lifted fuel valve operated from a damper throttle in conjunction with a fixed primary and automatic secondary air inlet is shown on page 419. (1,052,917, Feb. 11, 1913, Heitger.) A combination of separated fuel-inlet nozzle and regulating fuel valve, the latter operated from a damper throttle and the former associated with a fixed primary and automatic secondary air inlet, is shown on page 422. (1,096,569, May 12, 1914, Sharpneck.) The fixed primary and automatic secondary air inlets are used in combination with the rotating sleeve throttle turning a screw-threaded fuel valve in its fixed casing, on page 422. (1,106,226, Aug. 4, 1914, Lamb.) Use is made of the long taper fuel metering pin fixed to a flat block form of throttle on page 420 (1,106,802, Aug. 11, 1914, Goldberg), in connection with fixed primary and automatic secondary air inlets, but in such a way as to partially restrict the primary air passage. On page 420 (1,173,762, Feb. 29, 1916, Arquembourg), a regulating fuel valve cam operated from the shaft of a barrel throttle is combined with a fuel nozzle located in a Venturi throat, beyond which the secondary air enters through ball-type automatic valves.

Subclass 13.5—Valve fuel inlet, fixed primary and automatic valved secondary air inlets, fuel valve controlled by the automatic secondary air valve.—Assuming that the old standard fixed fuel and primary air carburetor with automatic secondary air compensation to be inadequate for the severe conditions of the variable-speed engine, and that some additional means of compensation is necessary, then it is quite a natural and logical step to make this take the form of a fuel valve adjustment controlled by the secondary air valve on the ground that up to the time the latter opens the fuel area should vary with the additional air area, or that both areas should be controlled by the vacuum. This seems to be the origin of the ideas of the cases of this subclass, one of the earliest of which is that on page 421. (855,170, May 28, 1907, Gray.) A direct connection is made between the automatic secondary air valve and the fuel valve, so both move the same amount in this case. A bell-crank linkage is provided to connect a horizontal-stem automatic air valve and a vertical-stem fuel valve on page 421. (981,853, Jan. 17, 1911, Halladay.) Location of the fuel needle on the axis of the automatic air valve, the stem guide of which is tubular and serves as the fixed primary air inlet, is illustrated on page 421. (1,010,185, Nov. 28, 1911, Schulz.) A tubular sleeve form of fuel valve, forming the stem guide of the secondary air valve, is shown on page 421. (1,022,702, Apr. 9, 1912, Rothe & Culp.) A cam connection between the automatic air valve and the fuel needle is shown on page 423 (1,078,590, Nov. 11, 1913, Muir), which also illustrates the idea of a throttle limit to the movement, so that, while it is automatic and completely so for a wide-open throttle, it is not for a partly closed throttle, and at any time closure of the throttle closes both fuel and secondary air valves. Two fuel valves operated by the automatic air valve are shown on pages 423 and 424 (1,111,224, Sept. 22, 1914, Hamilton), but so located as to act as one, so far as proportionality is concerned. Of course, two different fuels can be simultaneously used. A lever connection between the secondary air valve and the fuel valve is shown on page 424 (1,118,126, Nov. 24, 1914, Harroun), which also has electrical heating coils in the primary air tube in-

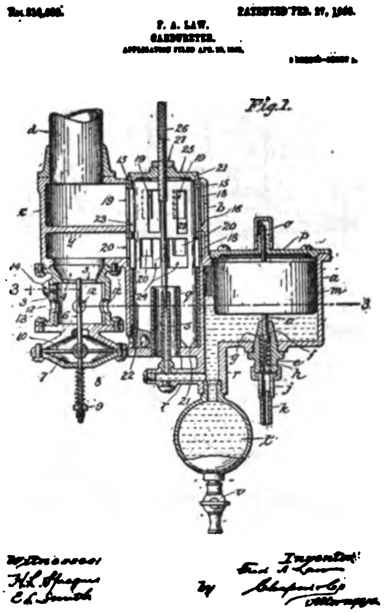
tended to adapt it to kerosene. It is of interest to compare this with the same proportionality arrangement adapted to use exhaust heat both for warming the primary air and for directly heating the primary mixtures, as shown on page 424 (1,158,494, Nov. 2, 1915, Harroun), to which an air-valve dashpot is added as well.

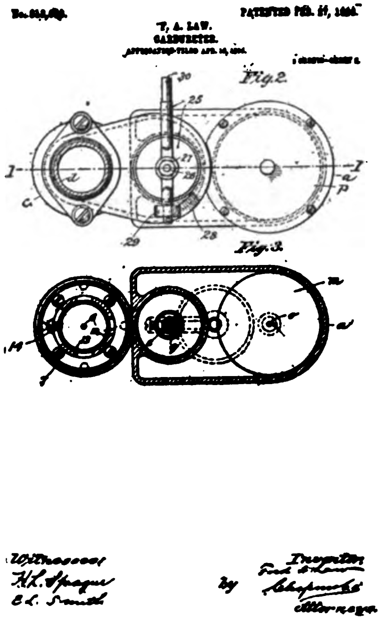
Use of a very much restricted primary air venturi, as illustrated on page 425 (1,156,823, Oct. 12, 1915, Schebler), hardly more than will serve to lift the fuel and to somewhat spray it. This brings this subclass very close, indeed, to that of subclass 12.5, with all its favorable functional characteristics. It is an excellent example of the way in which one class merges into another, and necessarily so, no matter what the classification basis may be.

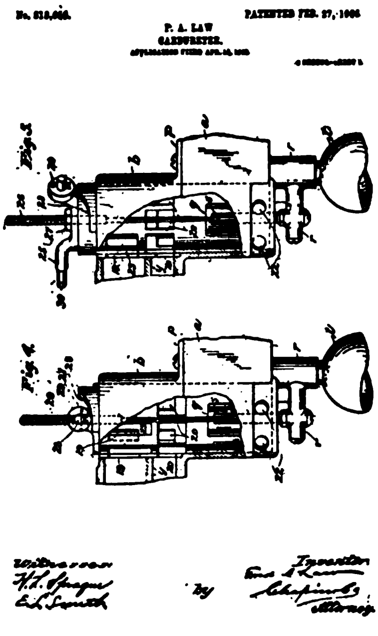
Subclass 13.6—Valved fuel inlet, valved primary and secondary air inlets, both automatic, fuel valve controlled by one or both automatic air inlet valves.—In essential principle this subclass is the same as that of subclass 7.5, though structurally the difference is real, being that of two valves versus one. Of course, if the valves are different, especially in size and loading, then control of the fuel valve does not so directly proportion fuel to total air as with two similar valves which would be equivalent to one. If one such valve will serve the purpose, some other reason than a search for proportionality must be responsible, and one reason that certainly applies in some cases is a failure to realize the fact.

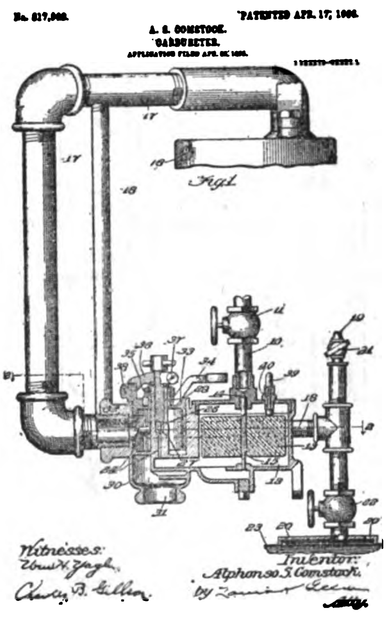
Two spring-loaded automatics, nearly similar, are used on page 426 (917,125, Apr. 6, 1909, Pierce), one of them controlling the fuel valve by a cam surface on its stem. This one is fitted with a throttle resistance, while the other is free. A pair of swing checks of different size are both connected to a bell-crank needle-valve control, and they therefore act as one on page 426. (1,022,326, Apr. 2, 1912, Namur.) Four small spring-loaded secondary air valves are added to a central automatic piston sleeve primary automatic, controlling the fuel-metering pin, on page 426. (1,084,954, Jan. 20, 1914, Nice.) A single piston and sleeve form of automatic valve controls two sets of air ports, the one above acting as secondary and a lower annual port as primary air passage. The moving member adjusts the fuel valve at the same time on page 427. (1,087,187, Feb. 17, 1914, Schulz.) The primary air is small and is a convenient means of lifting and spraying the fuel. The action is entirely equivalent functionally to the previous class referred to. As arranged on page 428 (1,105,134, July 28, 1914, Hanemann) the primary automatic air valve controlling the fuel valve is entirely different from the secondary, and the action must also be different with respect to proportionality.

On page 427 (1,125,525, Jan. 19, 1915, Hathcote, is shown a form that again illustrates how closely one class merges into another, this case being, except for the proportion of the fixed to the valve controlled air, similar to those of subclass 12.5 more especially those examples of that class that have a small fixed air passage passing the fuel inlet for idling and for lifting the fuel into the main air stream, but not enough air to be considered as removing complete air control from the automatic valve. Here the central fixed hole is too large to be ignored in this way, but it would be impossible to draw a line of division with precision.

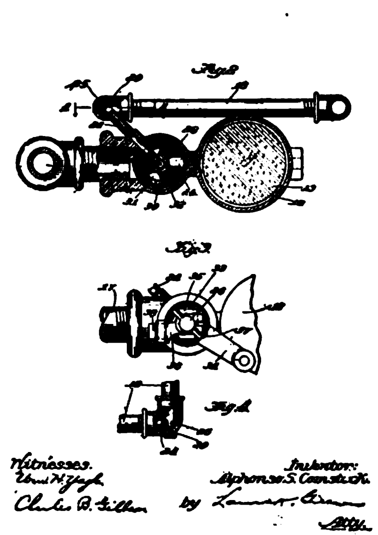

PATENTED FEB. 27, 1906.
F. A. LAW.
CARBURETER.
Fig.1.
Witnesses:
H. L. Sprague
E. L. Smith
Inventor:
by
Attorneys


F. A. LAW.
CARBURETER.
Fig.2.
Fig.3.
Witnesses:
H. L. Sprague
E. L. Smith
Inventor:
by
Attorneys

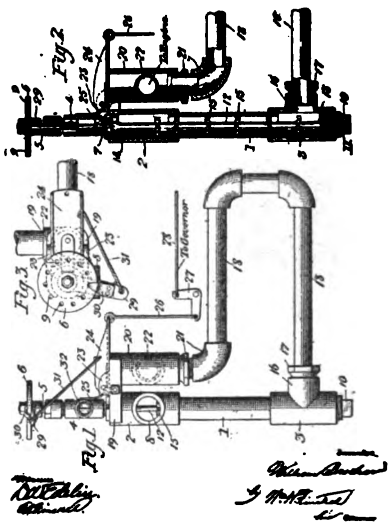

PATENTED FEB. 27, 1906.
F. A. LAW
CARBURETER.
Fig.3.
Fig.4.
Witnesses:
H. L. Sprague
E. L. Smith
Inventor:
by
Attorney


PATENTED APR. 17, 1906.
A. S. COMSTOCK.
CARBURETER.
Fig.1.
Witnesses:
Inventor:
Alphonso S. Comstock.

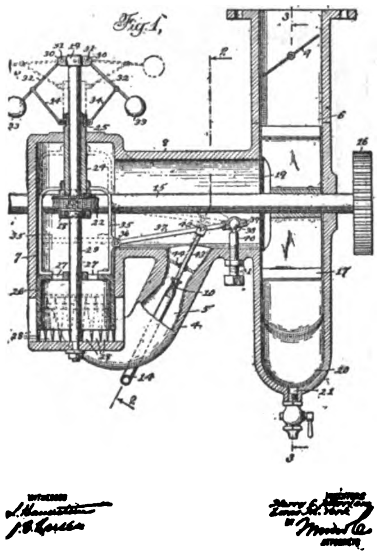
No. 817,966. PATENTED APR. 17, 1906.
A. S. COMSTOCK.
CARBURETER.



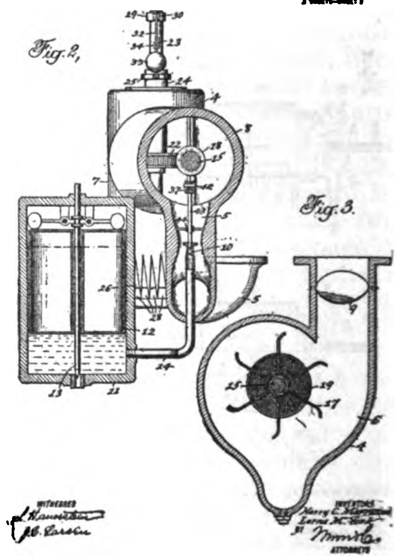
No. 876,319. PATENTED JAN. 14, 1908.
W. BROTHERS.
CHARGE FORMING DEVICE FOR INTERNAL COMBUSTION ENGINES.



H. C. MERRIAM & L. M. YORK.
CARBURETER.
1,154,580. Patented Sept. 21, 1915.



H. C. MERRIAM & L. M. YORK.
CARBURETER.
1,154,580. Patented Sept. 21, 1915.

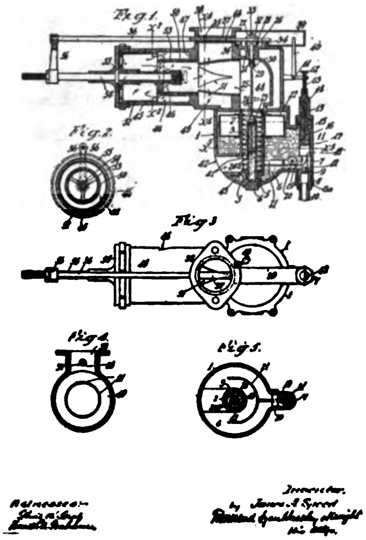


PATENTED APR. 28, 1908.

J. A. SPEED.

RAPID FIRE CARBURETER.

APPLICATION FILED [illegible]

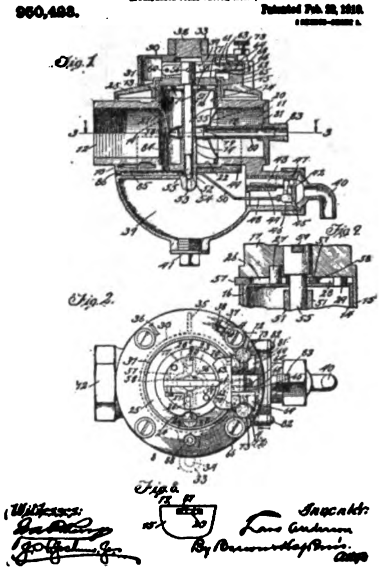


L. ANDERSON.

CARBURETER.

APPLICATION FILED FEB. 16, 1909.

950,493. Patented Feb. 22, 1910.

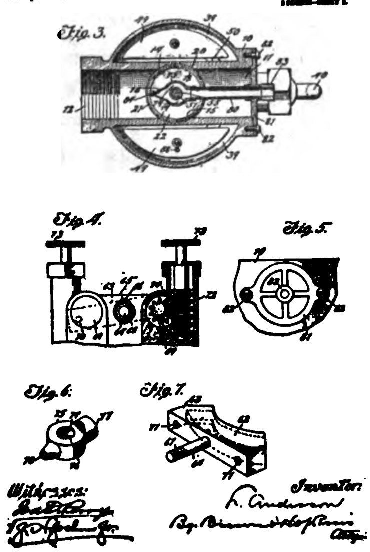


L. ANDERSON.

CARBURETER.

APPLICATION FILED FEB. 16, 1909.

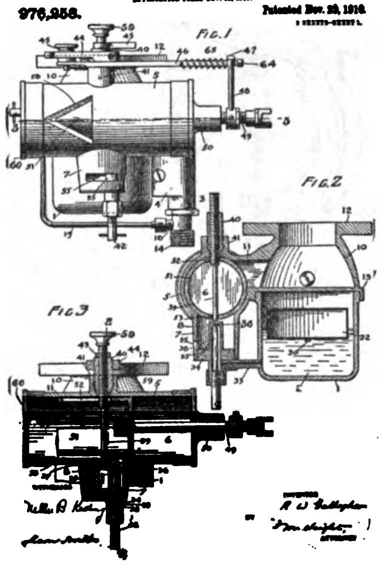
960,493. Patented Feb. 22, 1910.



R. W. GALLAGHER.

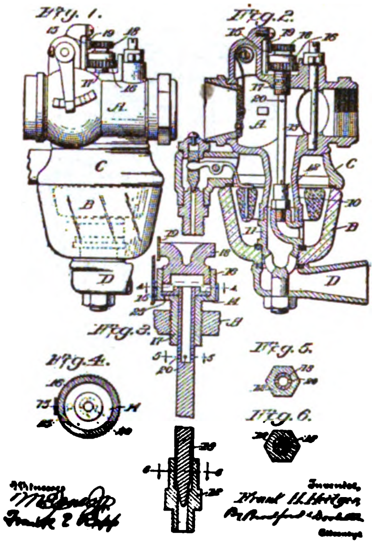
CARBURETER.

976,258. Patented Nov. 22, 1910.



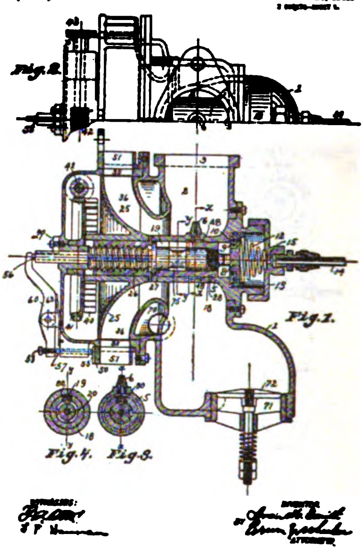
F. H. HEITGER.
CARBURETER.

1,188,964. Patented Mar. 28, 1916.



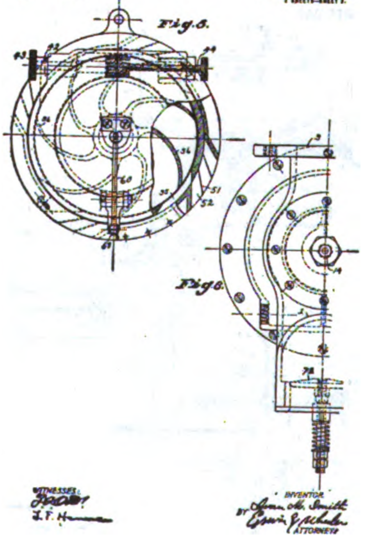
I. M. SMITH.
CARBURETER.

1,158,324. Patented Oct. 26, 1915.

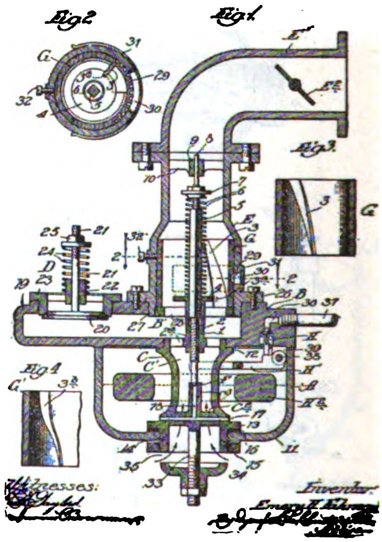


I. M. SMITH.
CARBURETER.
APPLICATION FILED AUG. 12, 1912.

1,158,324. Patented Oct. 26, 1915.
2 SHEETS—SHEET 2.

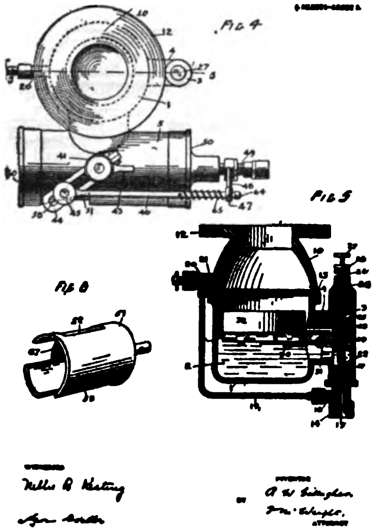


1,178,064. Patented Apr. 4, 1916.



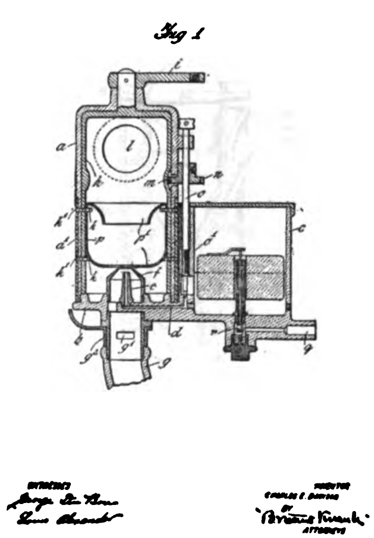
R. W. GALLAGHER.
CARBURETER.
APPLICATION FILED NOV. 16, 1908.

976,958. Patented Nov. 22, 1910.



C. E. DAWSON.
APPARATUS FOR PRODUCING AN EXPLOSIVE OR COMBUSTIBLE MIXTURE OF LIQUID FUEL AND AIR.
APPLICATION FILED MAR. 6, 1912.

1,029,796. Patented June 18, 1912.



C. E. DAWSON.
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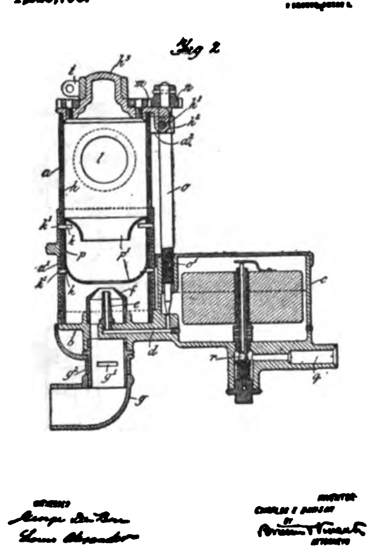
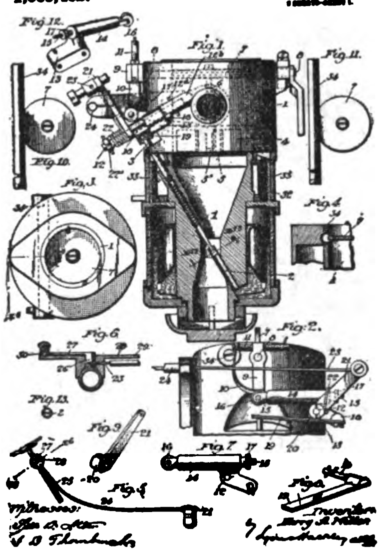
APPLICATION FILED MAR. 6, 1912.

1,029,796. Patented June 18, 1912.

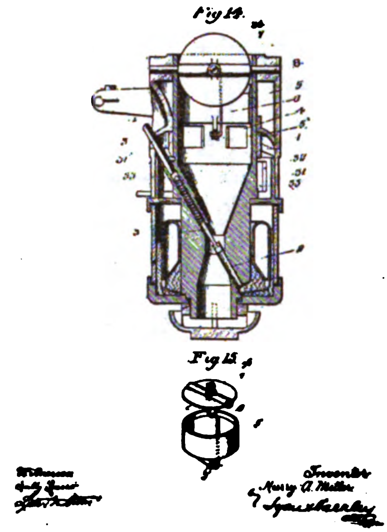


H. A. MILLER.
CARBURETER.
APPLICATION FILED JUNE 1, 1912.

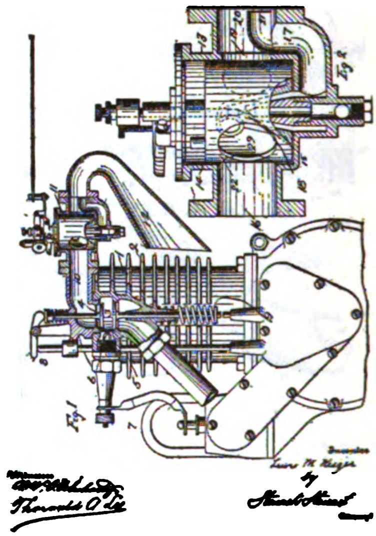
1,065,462. Patented June 24, 1913.



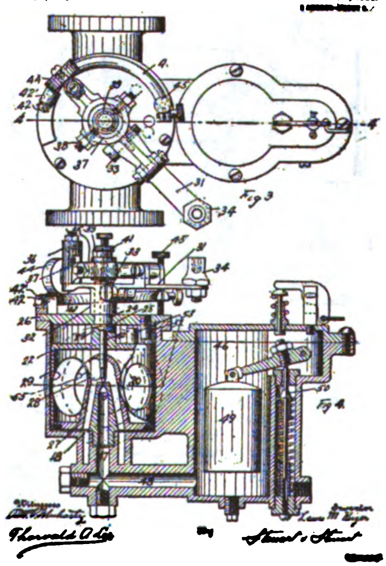
H. A. MILLER.
CARBURETER.
1,065,469. Patented June 24, 1913.



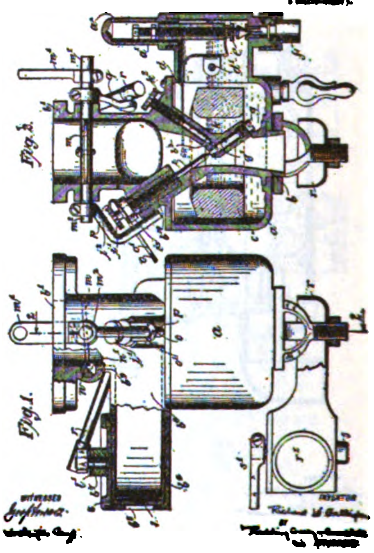
L. M. KIZER.
CARBURETER.
1,125,239. Patented Jan. 19, 1915.



L. M. KIZER.
CARBURETER.
1,125,239. Patented Jan. 19, 1915.



R. W. GALLAGHER.
CARBURETER.
1,148,485. Patented July 27, 1915.



R. W. GALLAGHER.
CARBURETER.
APPLICATION FILED AUG. 1, 1913.

1,148,485. Patented July 27, 1915.
2 SHEETS—SHEET 2.

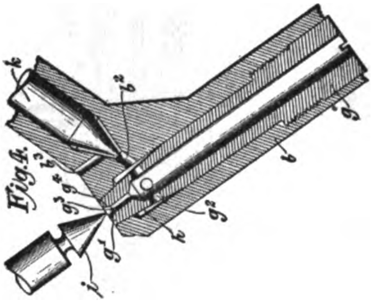


Fig. 4.

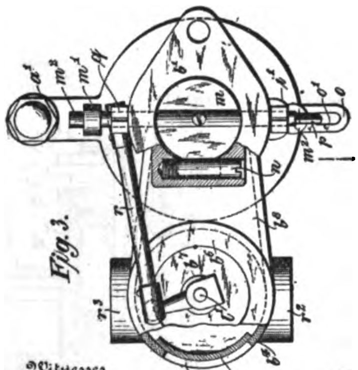


Fig. 3.

Witnesses

Inventor
Richard W. Gallagher
By his Attorneys

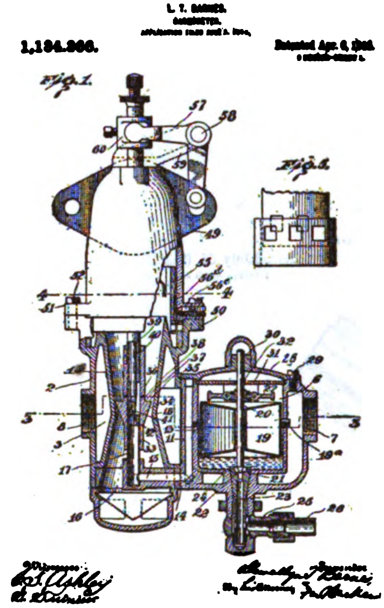


Fig. 1.
Fig. 3.
Witnesses:

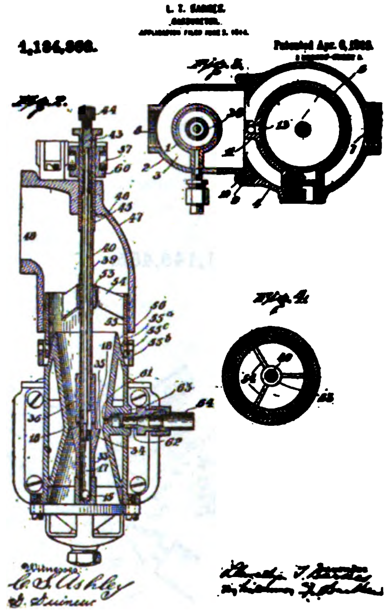
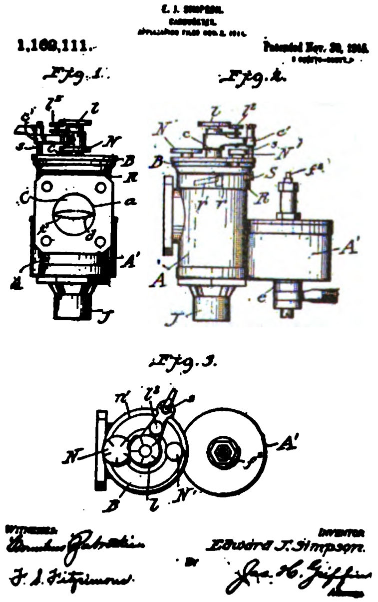
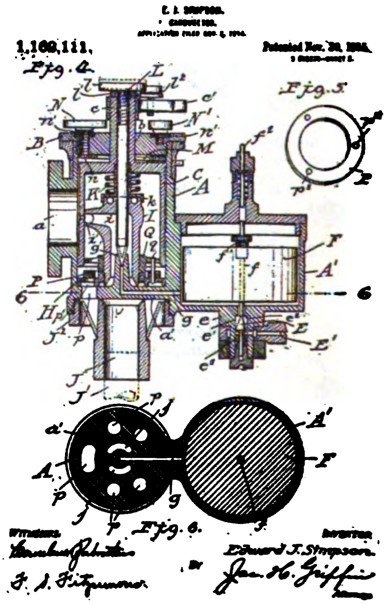


Fig. 2.
Fig. 5.
Fig. 4.
Witnesses:



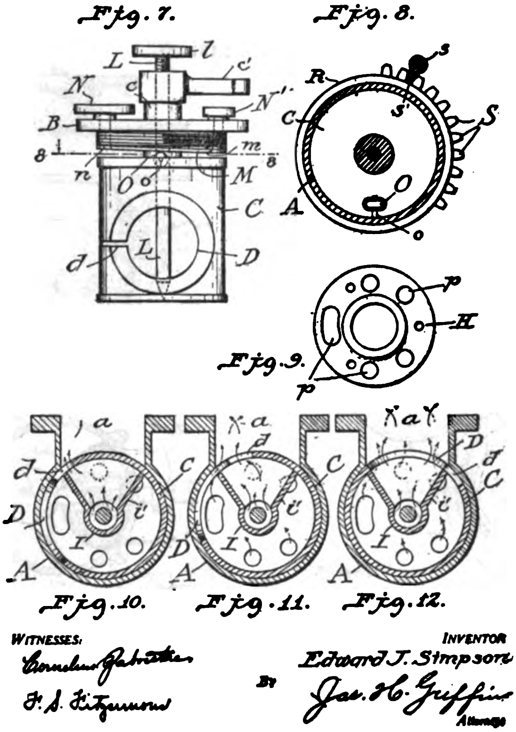
1,169,111.
Fig. 1.
Fig. 2.
Fig. 3.
WITNESSES
INVENTOR
Edward J. Simpson.
BY



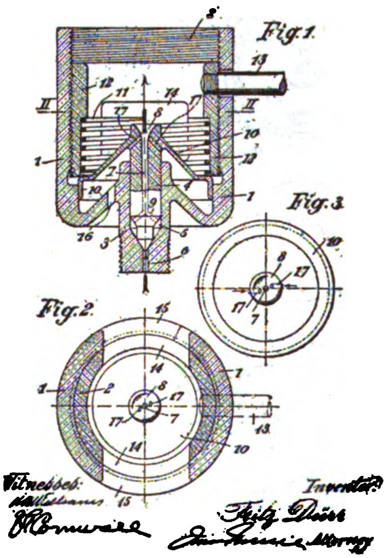
1,169,111.
Fig. 4.
Fig. 5.
Fig. 6.
WITNESSES
INVENTOR
Edward J. Simpson.
BY

E. J. SIMPSON.
CARBURETER.
APPLICATION FILED NOV. 2, 1914.

1,162,111. Patented Nov. 30, 1915.
3 SHEETS—SHEET 3.

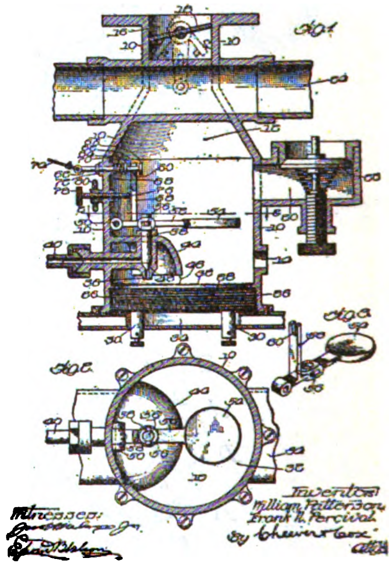


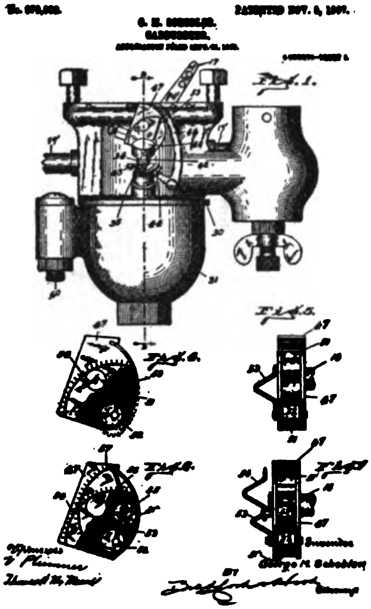
1,061,282.

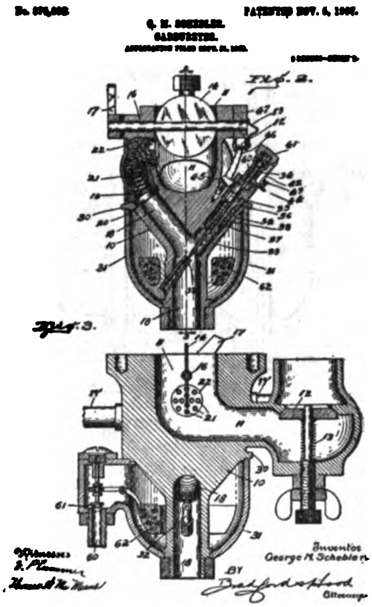


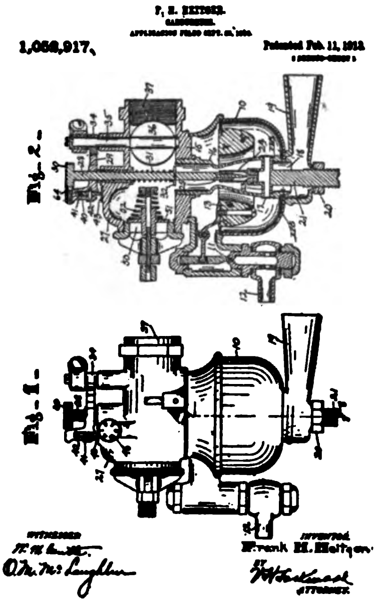
F. H. PERCIVAL & W. PATTERSON.

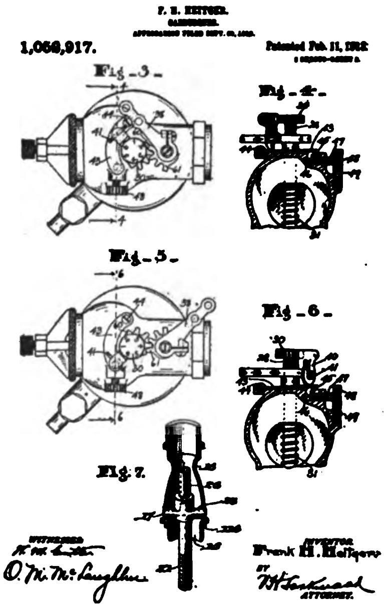
1,131,157.




George H. Schebler

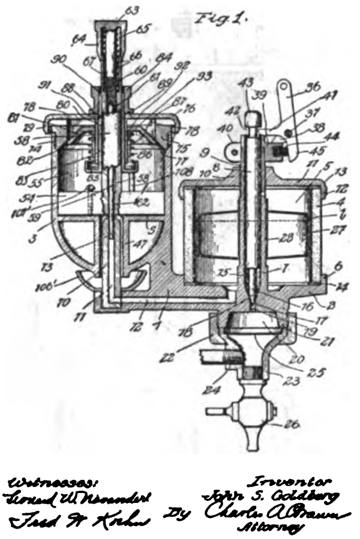

Inventor
George H. Schebler


1,056,917.
Fig. 2.
Fig. 1.
Frank H. Heitger


1,056,917.
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 6.
Fig. 7.
Frank H. Heitger

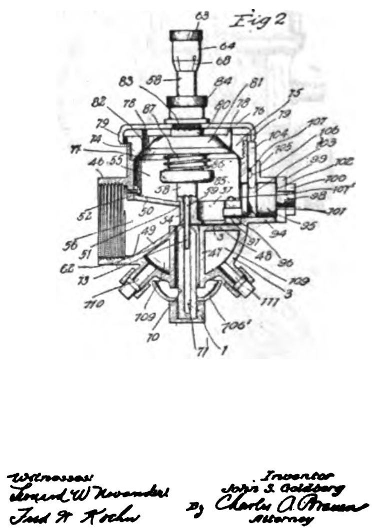
J. S. GOLDBERG.
CARBURETER.
APPLICATION FILED [illegible]

1,106,809. Patented Aug. 11, 1914.



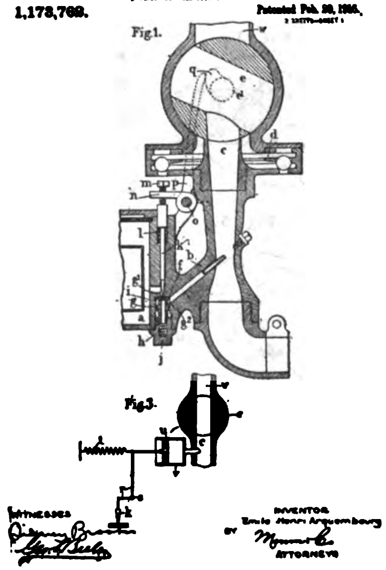
J. S. GOLDBERG.
CARBURETER.
APPLICATION FILED [illegible]

1,106,809. Patented Aug. 11, 1914.



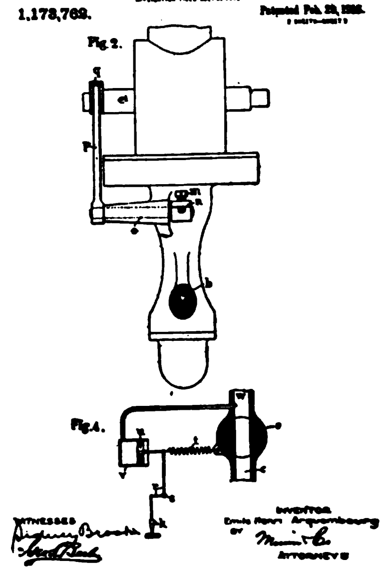
E. H. ARQUEMBOURG.
CARBURETER.
APPLICATION FILED [illegible]

1,173,769. Patented Feb. 29, 1916.



E. H. ARQUEMBOURG.
CARBURETER.
APPLICATION FILED [illegible]

1,173,769. Patented Feb. 29, 1916.

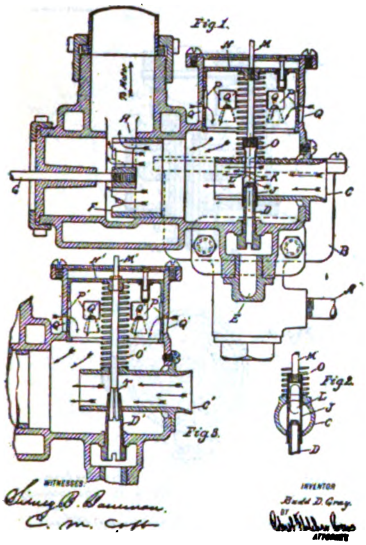


No. 923,170. PATENTED MAY 25, 1909.

B. D. GRAY.

CARBURETER.

APPLICATION FILED JULY 14, 1908.

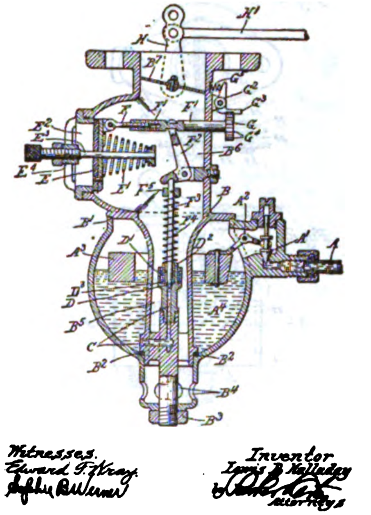


L. P. HALLADAY.

CARBURETER.

APPLICATION FILED OCT. 4, 1909.

981,853. Patented Jan. 17, 1911.

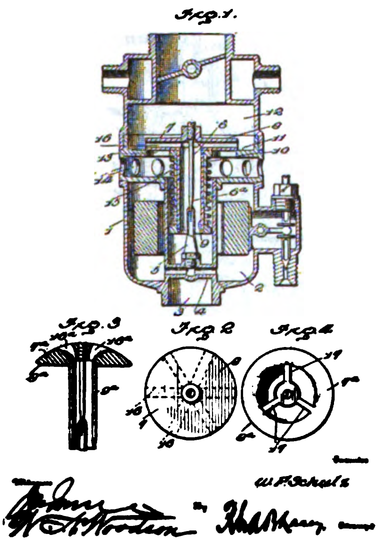


W. F. SCHULZ.

CARBURETER.

APPLICATION FILED APR. 24, 1909.

1,010,185. Patented Nov. 28, 1911.

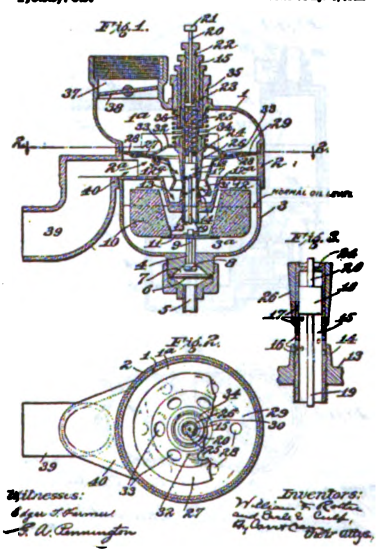


W. F. ROTHE & E. E. CULP.

CARBURETER.

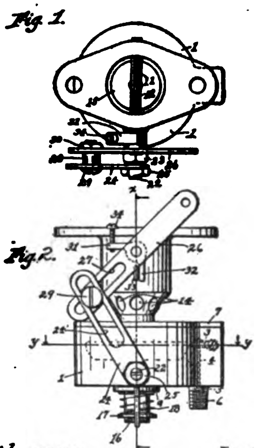
APPLICATION FILED FEB. 21, 1911.

1,022,702. Patented Apr. 9, 1912.



F. A. SHARPNECK.
CARBURETER.

1,096,569. Patented May 12, 1914.

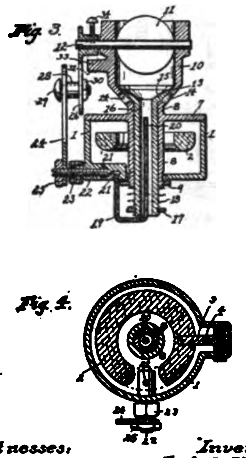


Witnesses:
G. Colson,
B. G. Richards

Inventor:
Frank A. Sharpneck,
By Joshua R. H. Potts
his Attorney.

F. A. SHARPNECK.
CARBURETER.

1,096,569. Patented May 12, 1914.

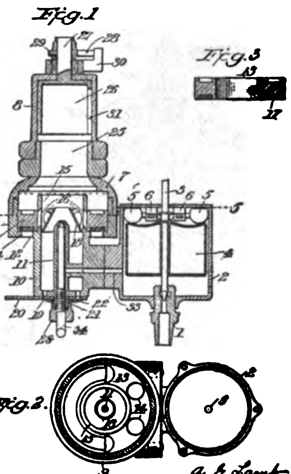


Witnesses:
G. Colson,
B. G. Richards

Inventor,
Frank A. Sharpneck,
By Joshua R. H. Potts
his Attorney.

A. G. LAMB.
CARBURETER.

1,106,296. Patented Aug. 4, 1914.

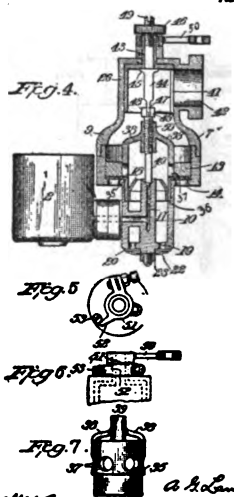


A. G. Lamb

Stuartvant & Mason

A. G. LAMB.
CARBURETER.

1,106,296. Patented Aug. 4, 1914.

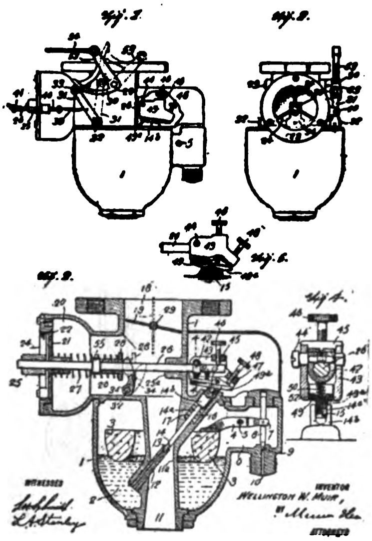


A. G. Lamb

Stuartvant & Mason

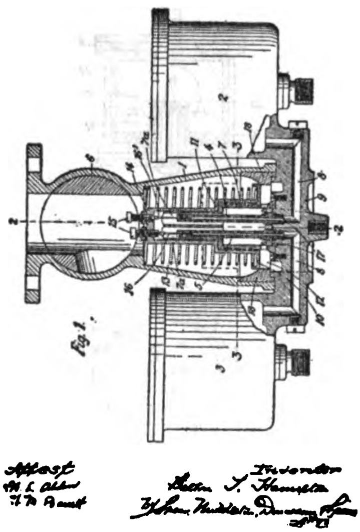
W. W. MUIR.
CARBURETER.
APPLICATION FILED JUNE 14, 1912.

1,078,590. Patented Nov. 11, 1913.



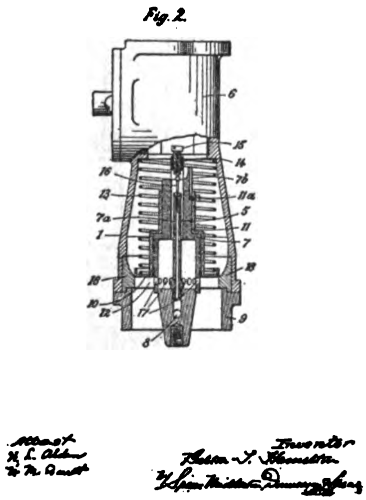
B. T. HAMILTON.
CARBURETER.
APPLICATION FILED MAR. 17, 1913.

1,111,294. Patented Sept. 22, 1914.
4 SHEETS—SHEET 1.



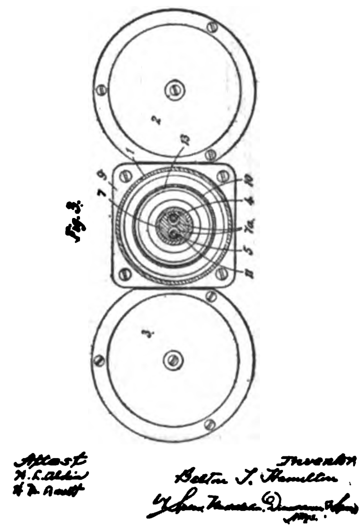
B. T. HAMILTON.
CARBURETER.
APPLICATION FILED MAR. 17, 1913.

1,111,294. Patented Sept. 22, 1914.
4 SHEETS—SHEET 2.



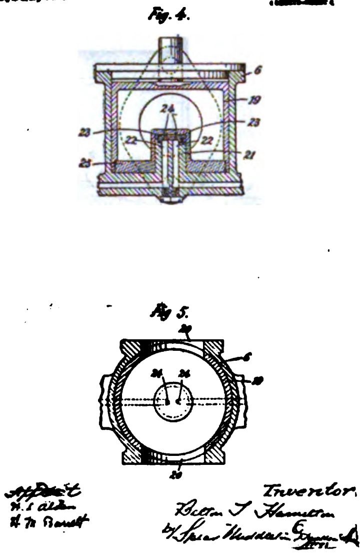
B. T. HAMILTON.
CARBURETER.
APPLICATION FILED MAR. 17, 1913.

1,111,294. Patented Sept. 22, 1914.
4 SHEETS—SHEET 3.



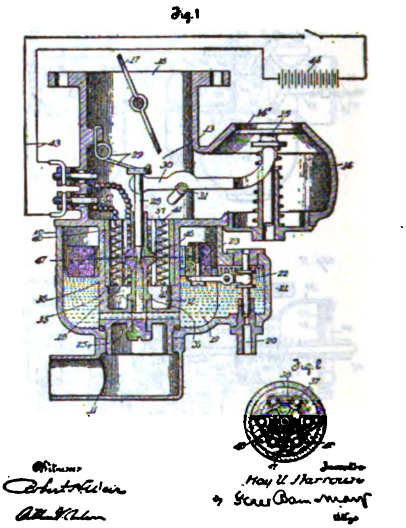
B. T. HAMILTON.
CARBURETER.

1,111,994. Patented Sept. 22, 1914.



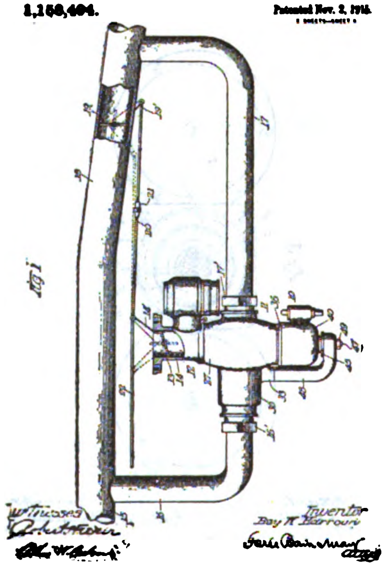
R. W. HARROUN.
CARBURETER.

1,118,196. Patented Nov. 24, 1914.



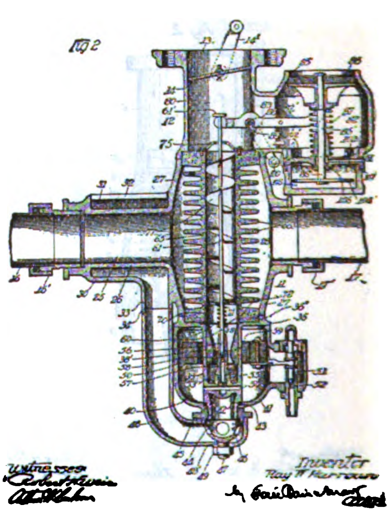
R. W. HARROUN.
CARBURETER.

1,158,494. Patented Nov. 2, 1915.



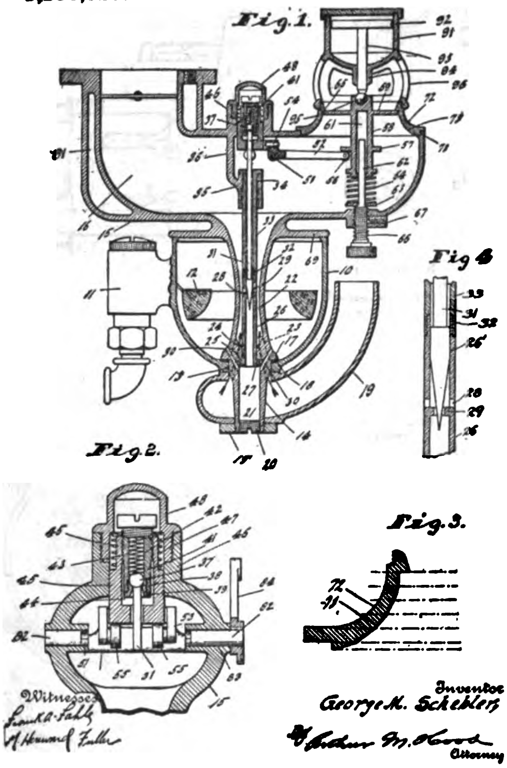
R. W. HARROUN.
CARBURETER.

1,158,494. Patented Nov. 2, 1915.



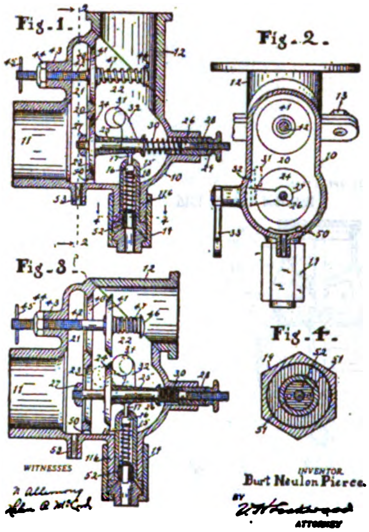
G. M. SCHEBLER.
CARBURETER.
APPLICATION FILED FEB. 8, 1912. RENEWED SEPT. 4, 1913.

1,156,823. **Patented Oct. 12, 1915.**



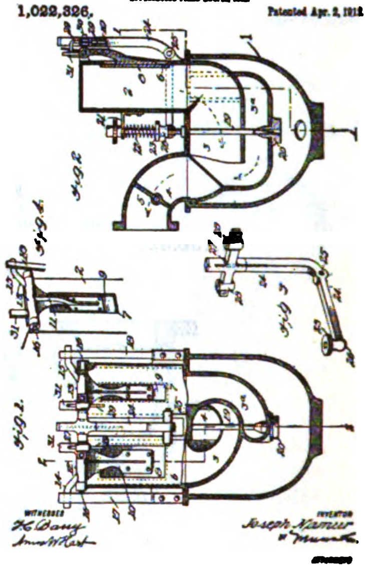
B. N. PIERCE.
CARBURETER.

917,195. Patented Apr. 6, 1909.



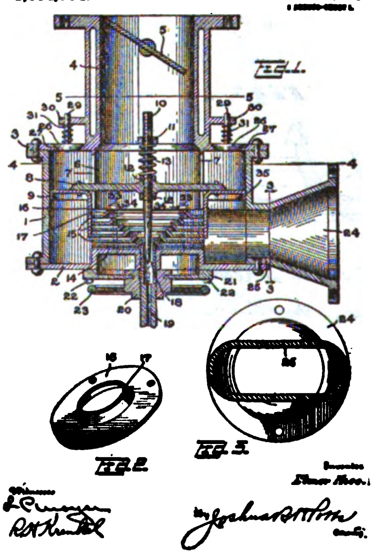
J. NAMUR.
CARBURETER.

1,022,326. Patented Apr. 2, 1912.



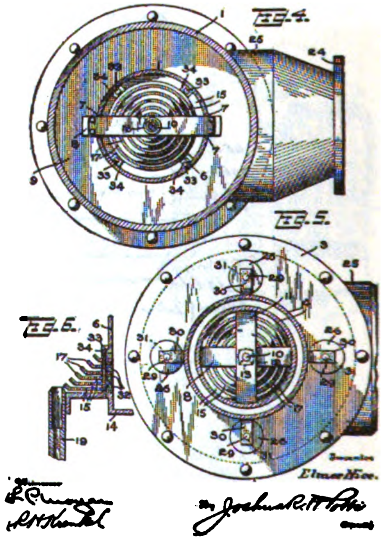
E. NICE.
CARBURETER.

1,084,954. Patented Jan. 20, 1914.



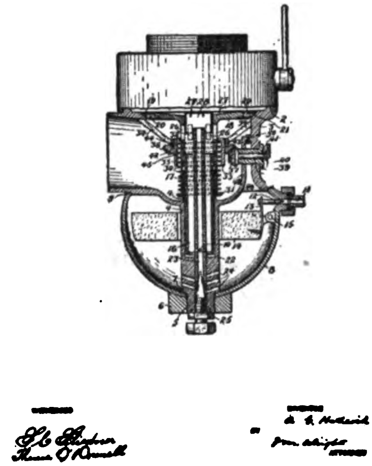
E. NICE.
CARBURETER.

1,084,954. Patented Jan. 20, 1914.



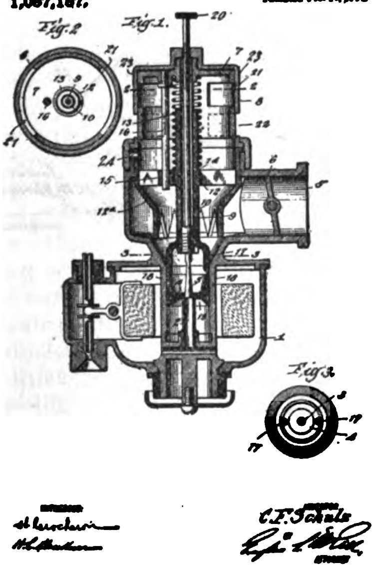
A. C. HATHCOCK.
CARBURETER.
APPLICATION FILED OCT. 3, 1912.

1,125,565. Patented Jan. 19, 1915.



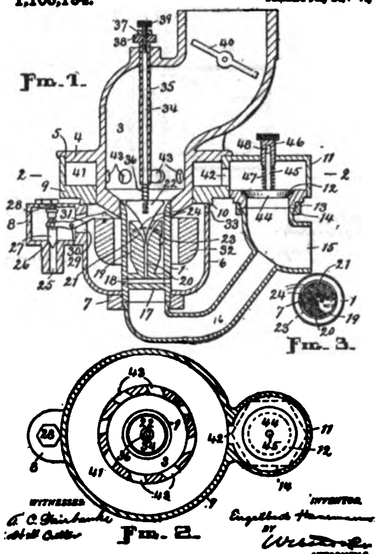
C. F. SCHULZ.
CARBURETER.
APPLICATION FILED MAR. 4, 1912.

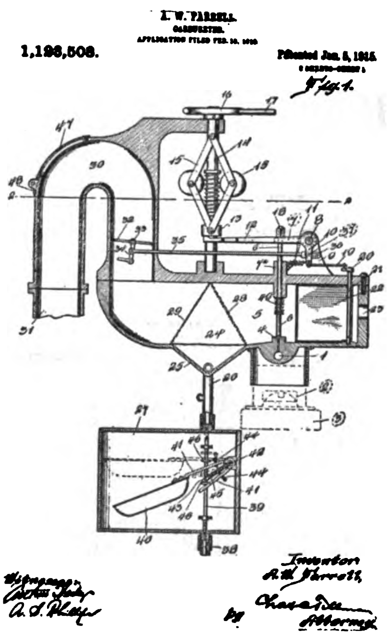
1,067,167. Patented Feb. 17, 1914.

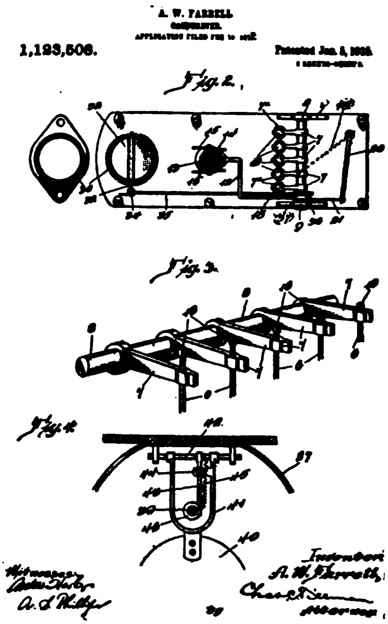


E. HANEMANN.
CARBURETER.
APPLICATION FILED NOV. 22, 1912.

1,105,184. Patented July 28, 1914.




1,123,506.
Fig. 1.


A. W. FARRELL.
1,123,506.
Fig. 2.
Fig. 3.
Fig. 4.

Class 14—Carburetors, proportioning flow, aspirating, multiple fuel and air inlets, both with regulating valves.—It would seem as if sufficient compensation could be secured by regulating fuel to air, or air to fuel, and certainly the opportunities are great with air and fuel both regulated even when there is only one inlet for each, without adopting a multiplicity of such, yet this is done in the cases of this class. However, the situation is not as complex as it might seem, because in the first place there are not many such cases, and second, these all fall into two groups, the high and low speed group or the multiple duplicate carburetor group, each of which constitutes a subclass.

On page 428 (1,123,508, Jan. 5, 1915, Farrell), a series of five fuel needles is arranged across an air passage, and they are operated from a single rocker shaft by lever arms set at slightly different angles, so that they open in succession and once open continue to increase the fuel-flow area as later ones come in. This rock shaft is linked to the throttle and to a swing type of air-inlet valve, the entering air sweeping successively the fuel jets as they come into action.

Subclass 14.1—Two fuel inlets, one fixed and one valved supplementary high-speed jet, two air inlets, one fixed primary and one valved secondary.—A single air inlet fitted with a damper type of valve, acting in the dual capacity of throttle and air valve has a hole in it, through which projects a fixed fuel nozzle for low-speed mixed flow. The damper motion controls a single variable fuel valve with multiple outlets in the combination on page 431. (1,038,040, Sept. 10, 1912, Weiss.) As the air valve swings open the fuel valve is opened and at the same time the air sweeps past the multiple outlets in varying degrees so that at first some discharge fuel, while others take in spraying air that emerges with the fuel elsewhere, though all discharge fuel later. The fixed idling jet nozzle is perforated so that it acts as a mixed-flow passage when the throttle is closed or nearly closed.

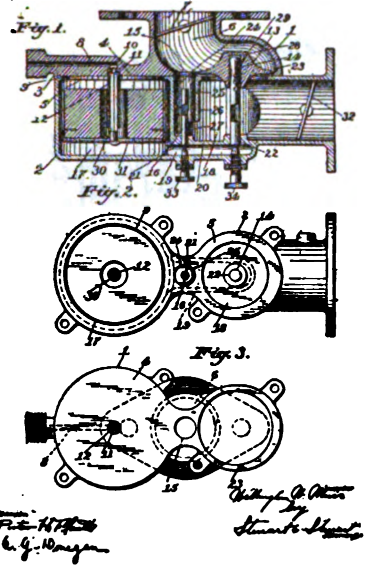
Two air inlets are provided on page 431 (1,164,661, Dec. 21, 1915, Muir), one fixed and one variable, the former with a fixed fuel inlet for low speed, the latter with a fuel valve controlled by the automatic air valve for higher speeds. This is another example of how closely classes merge one into another, for if the fixed air passage were closed or nearly so, it could be regarded as a low-speed or idling jet for a carburetor of the single variable fuel and air class. This would be the case also if the fixed jet were subjected to the same vacuum influence as the main jet, because then it would be a multiple outlet single jet instead of a multiple jet. A small fixed fuel and air inlet for low speed delivers beyond a main barrel throttle on page 432 (1,172,031, Feb. 15, 1916, Morand), the main passage consisting of fixed primary air, with secondary and fuel valve controlled by the throttle. Two air passages, a primary with a ball form of automatic air valve, and the other or secondary with a damper air valve, associated with two fuel nozzles, are shown on page 422. (1,179,381, Apr. 11, 1916, Sunderman.) A linkage connects the high-speed fuel-inlet valve and the secondary air damper to the throttle. Graduation of the high-speed fuel inlet by the movement of a secondary automatic air valve, is illustrated on page 433 (1,179,386, Apr. 18, 1916, Anderson), in connection with a fixed low-speed jet in a fixed primary air inlet.

Subclass 14.2—Multiple carburetors, progressive, by throttle or vacuum.—A series of eight fuel inlets, each with a regulating valve and each in a separate passage, the air to which varies with the throttle outlet from it, are combined in one casing by using a multi-ported barrel sleeve for all air valves and throttle, the separate passages being formed within it, as shown on page 434. (1,120,184, Dec. 8, 1914, Duff.) A separate idling fixed jet and air inlet are provided beyond the throttle.

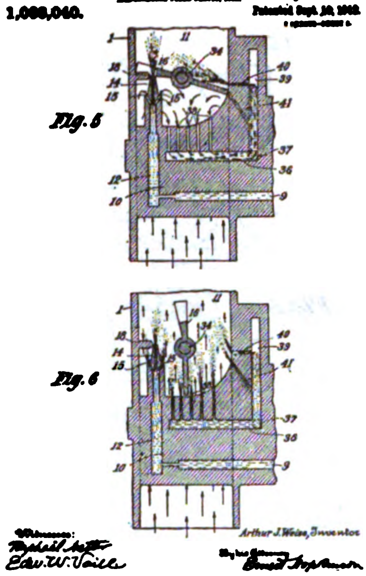
Class 15—Carburetors, proportioning flow, aspirating, thermostatic, or barometric controlled.—Assuming that a carburetor of any class whatever works satisfactorily at a given place under constant conditions of temperature and barometric pressure, it does not follow that the operation will continue to be satisfactory when the surrounding temperature or the barometric pressure changes. Of course, these variations exert a certain influence on the vaporization characteristics of the fuel, acting directly on its vapor pressure on the one hand and on the relation of the partial pressure of the vapor in the mixture to that of the air on the other, when the total pressure changes without a change of vapor pressure. These vaporization difficulties, while serious enough in themselves, are not now under discussion, attention being for the present concentrated on the proportionality problem, which is fundamental. Anything that changes the density of air will change the flow through a given passage under the influence of a given pressure drop, so that given a fixed vacuum on a fixed carburetor air passage, the amount that will flow depends on the air density, and as air density changes so will the flow change. As both absolute pressure and air temperature exert direct effects on air density, changes in them will directly cause a change in flow, the amount of which may be very considerable. This is undoubtedly greater in aero work than elsewhere, because a machine may leave sea level and in climbing reach altitude where the barometric pressure is half its previous sea-level value, a density effect of 50 per cent. At the same time the air temperature may drop from over 100° in southern or summer districts to something below zero in the high air, which correspond roughly to a density change of 20 per cent in order of magnitude in the opposite sense. From considerations such as this it becomes clear that carburetors might very properly be provided with automatic compensation for air-density changes, and that such should be provided for all those used in aero work.

Similarly, the flow capacity of a fuel passage, whether its characteristics are those of the orifice or of the capillary, depends on the viscosity of the fuel and may vary very much, indeed enough to make the difference between success and failure if the viscosity varies over the whole range that is possible with normal temperature changes, especially in those cases where heat is being applied to properly vaporize the heavier fuels or in using varying mixtures of differently viscous fuels, or two such in succession, through the same passage. Neglecting the latter condition as one requiring special treatment and concentrating on temperature change, it is clear, as in the case of the air, that temperature variations in the fuel must not be permitted to exceed a value fixed by the viscosity—temperature curve of the fuel that would result in appreciable flow changes, say, 5 per cent as a limit. This will correspond to quite a different tem-

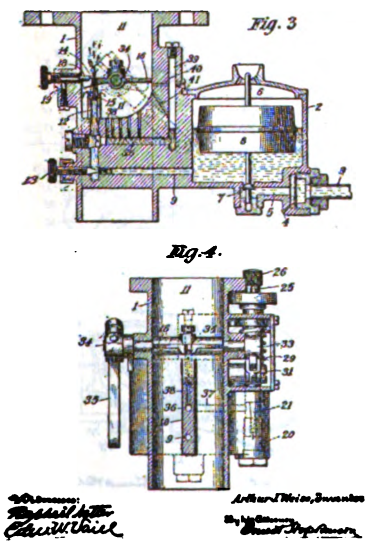
1,164,661.



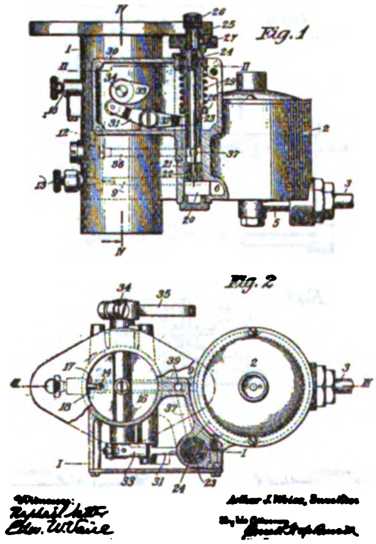
1,068,040.



1,068,040.

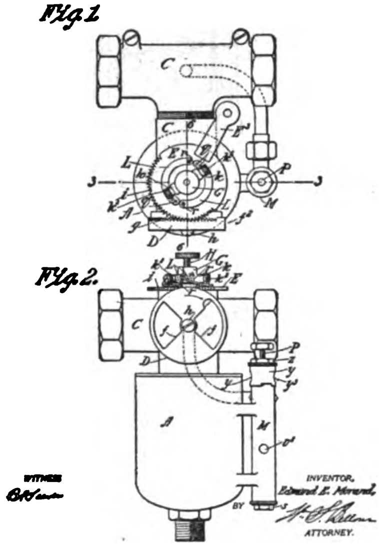


1,068,040.



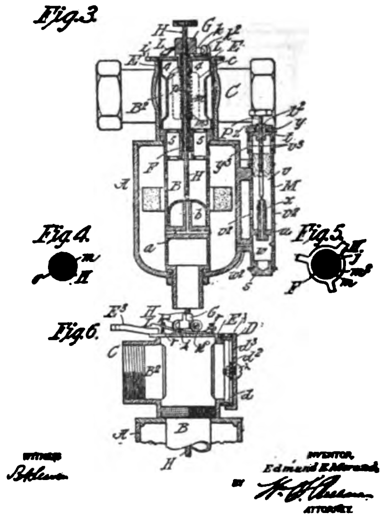
E. E. MORAND.
CARBURETER.

1,172,081. Patented Feb. 15, 1916.



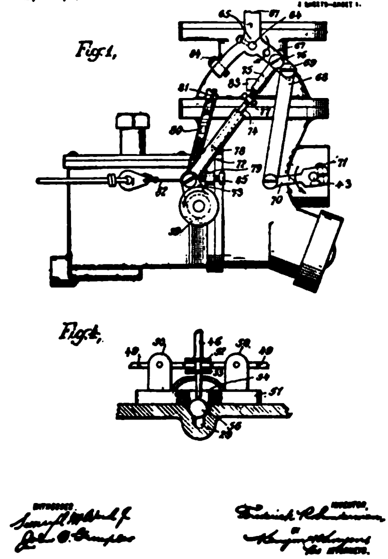
E. E. MORAND.
CARBURETER.

1,172,081. Patented Feb. 15, 1916.



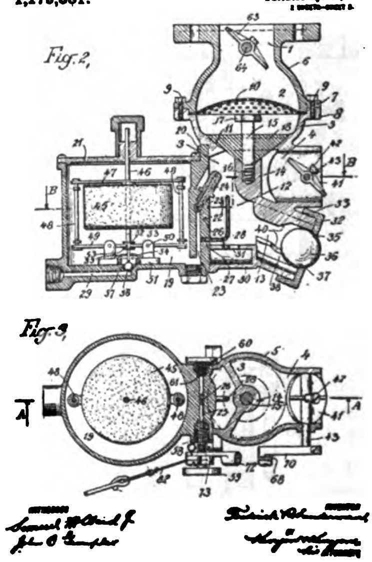
F. R. SUNDERMAN.
CARBURETER.

1,179,881. Patented Apr. 11, 1916.



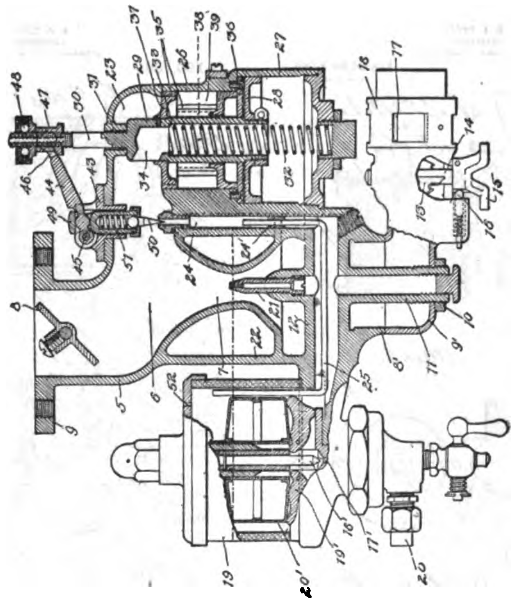
F. R. SUNDERMAN.
CARBURETER.

1,179,881. Patented Apr. 11, 1916.



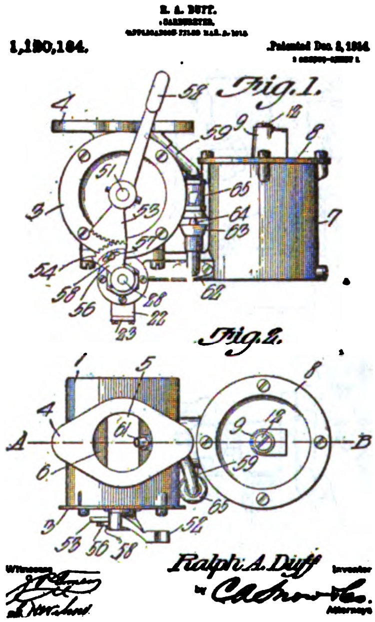
R. M. ANDERSON.
CARBURETER.
APPLICATION FILED MAY 27, 1912.

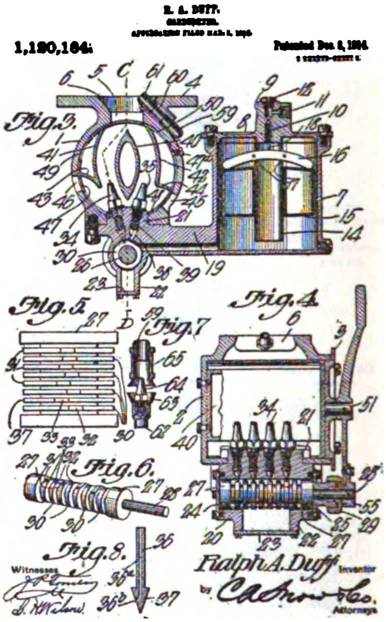
1,179,386. Patented Apr. 18, 1916.



Witnesses,
Leslie W. Fricke
Robert F. Bracke

Inventor
Raymond M. Anderson
By Brown & Williams
Attorneys.


R. A. DUFF.
CARBURETER.
1,120,164.
Patented Dec. 8, 1914.
Fig. 1.
Fig. 2.
Witnesses
Ralph A. Duff
Inventor
by C.A. Snow & Co.
Attorneys


R. A. DUFF.
CARBURETER.
1,120,164.
Patented Dec. 8, 1914.
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 6.
Fig. 7.
Fig. 8.
Witnesses
Ralph A. Duff
Inventor
by C.A. Snow & Co.
Attorneys

perature range in the case of one fuel as compared with another. Equivalent to control of this temperature range for the fuel, which may not, and in some cases is not practical as interfering with vaporization, is, of course, compensation for it by control of vacuum or flow area.

There are not many patents on this subject of temperature change compensation or correction for air and fuel, or on barometric compensation for air, but it must be remembered that the realization of necessity is recent, and more may be expected along this line.

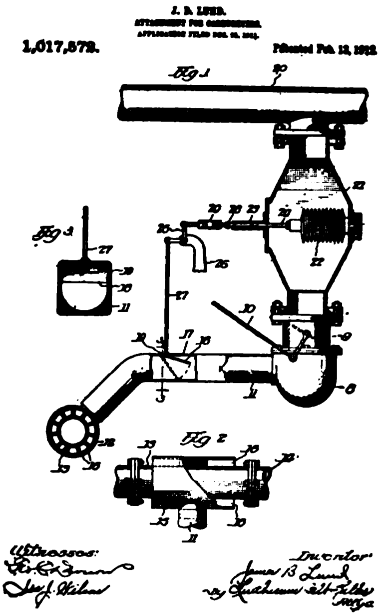
Subclass 15.1—thermostatic controls.—This sort of control may fall properly into two classes, one seeking automatically to keep the temperature from changing, and the other compensating for a temperature change by control of air or fuel valves.

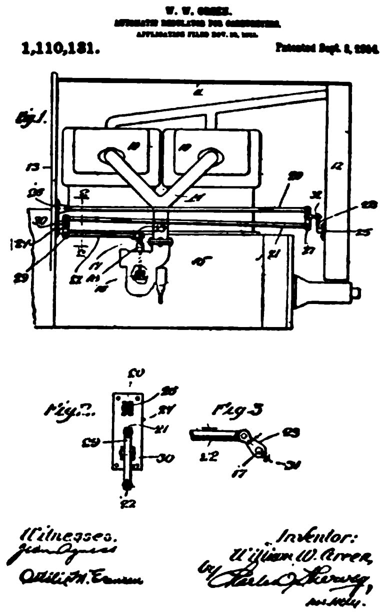
The first case, that on page 436 (1,017,572, Feb. 13, 1912, Lund), is an example of the former kind. Two sources of air are provided, one hot and the other cold, the ratio determining the temperature at the carburetor, and in the present case a single valve controls the ratio, the valve being actuated by the expansion or contraction of the walls of a body inserted in the path of the mixture. This thermostat is filled with a volatile liquid and has an expanding form of wall so the vapor pressure of this fluid is fixed by the main mixture temperature, but unfortunately the mixture pressure exerts a similar effect. Increase of vacuum due to a closed throttle, has the same effect on the movement as a rise of temperature, both causing the thermostat to expand.

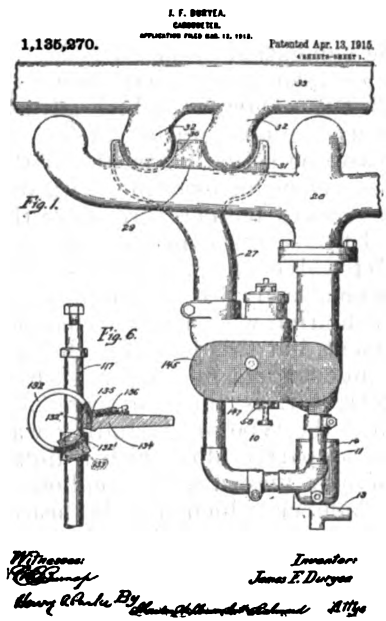
The second class of control, direct compensation by valve adjustment for temperature change, is illustrated on page 436. (1,110,131, Sept. 8, 1914, Green.) Here the air temperature changes operate the fuel needle valve by means of the elongation of metal rods. A more pertinent form of thermostatic compensator is that shown on pages 436 and 437 (1,135,270, Apr. 13, 1915, Duryea), which adjusts the fuel needle valve in accordance with the temperature of the air supplied to the carburetor. In this case the actuating means of the thermostat includes a closed tube, of mercury for example, with one end attached to a Bourdon tube. Changes of temperature cause the end of the Bourdon tube to move, and this adjusts the fulcrum of a lever between the automatic air inlet valve and the fuel needle, causing the latter to be adjusted automatically to air temperature without interfering with its normal regulation with air flow changes.

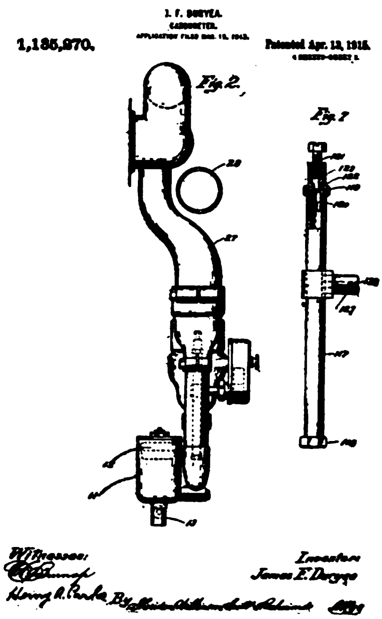
Another case of fuel needle adjustment, but this time for changes in the temperature of the fuel itself, independent of the air, such as could be regarded as a viscosity corrector, is that on page 437. (1,142,824, June 15, 1915, Lund.) Here the type of expanding wall chamber, filled with a liquid or a gas or partly filled with a liquid and partly with its vapor, now generally known as a syephon, is submerged in the fuel in a jacketed chamber, which may be heated or cooled. It has the fuel needle fixed directly to it and, as shown, it is suitable only for carburetors that otherwise have fixed fuel inlets.

One special case of thermostatic compensation of some practical value in dealing with fuels that are just over the border of volatility, vaporizing freely enough for use with warm air or by the heat of the passages leading to a warm engine, but not so when air and engine are cold, undertakes to solve the difficulty by opening the fuel valve at first and later closing it as the engine heats up. One of


1,017,879.
Fig 1
Fig 3
Fig 2
Witnesses:
Inventor
James B. Lund

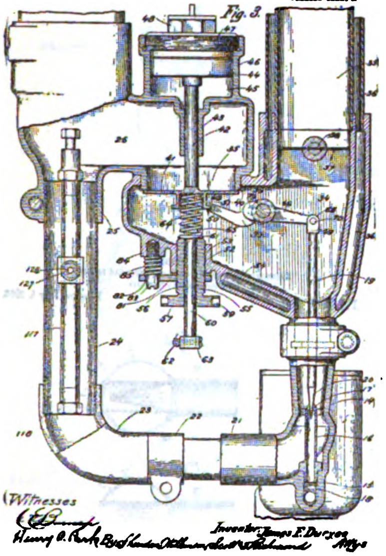

1,110,181.
Fig. 1.
Fig. 2.
Fig. 3
Witnesses.
Inventor:
William W. Green,
Ottilie M. Evanson


J. F. DURYEA.
CARBURETER.
APPLICATION FILED MAR. 12, 1913.
1,135,270.
Patented Apr. 13, 1915.
4 SHEETS—SHEET 1.
Fig. 1.
Fig. 6.
Witnesses:
Inventor:
James F. Duryea


J. F. DURYEA.
CARBURETER.
APPLICATION FILED MAR. 12, 1913.
1,135,270.
Patented Apr. 13, 1915.
Fig. 2.
Fig. 7
Witnesses:
Inventor:
James F. Duryea

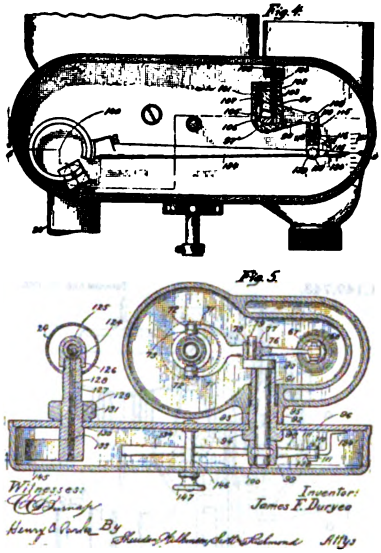
J. F. DURYEA.
CARBURETER.
APPLICATION FILED MAR. 12, 1912.

1,135,270. Patented Apr. 13, 1915.
4 SHEETS—SHEET 3.



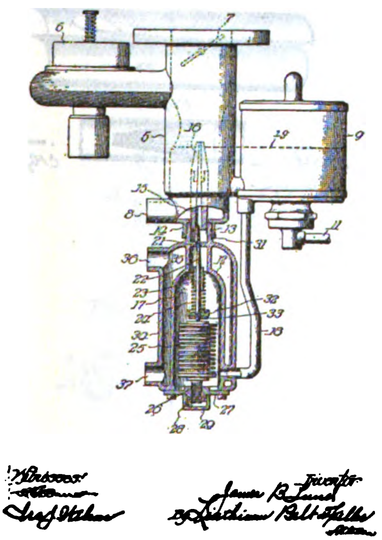
J. F. DURYEA.
CARBURETER.
APPLICATION FILED MAR. 12, 1912.

1,135,270. Patented Apr. 13, 1915.
4 SHEETS—SHEET 4.



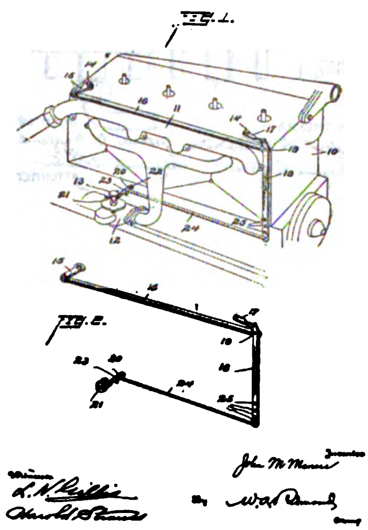
J. B. LUND.
CARBURETER ATTACHMENT.
APPLICATION FILED AUG. 12, 1913.

1,142,824. Patented June 15, 1915.



J. M. MANESS.
GAS ENGINE ATTACHMENT.
APPLICATION FILED OCT. 21, 1914.

1,133,872. Patented Mar. 30, 1915.



1,140,743.

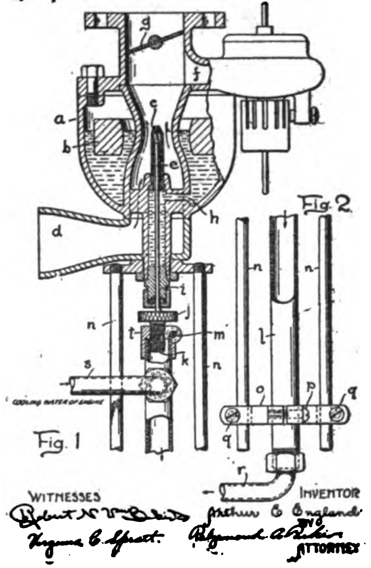


Fig. 1
Fig. 2
WITNESSES
INVENTOR
ATTORNEY

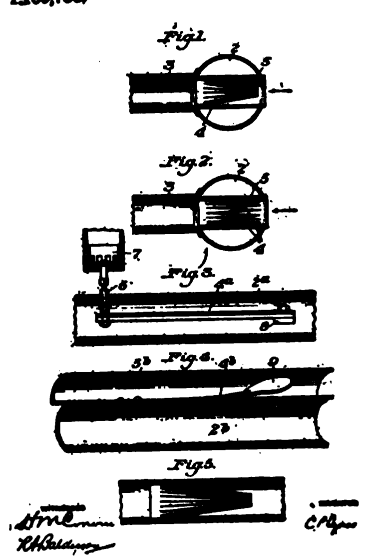
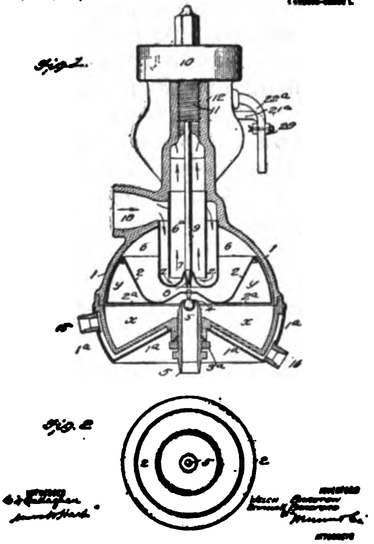


Fig. 1
Fig. 2
Fig. 3
Fig. 4
Fig. 5

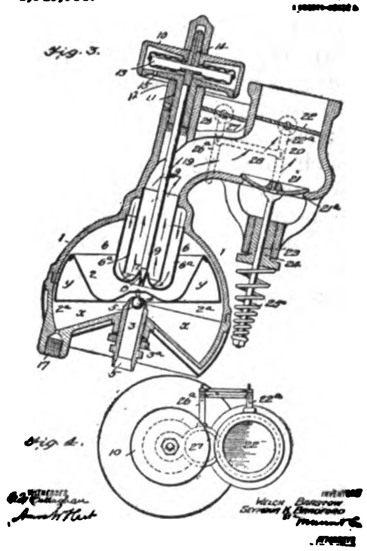
W. BARSTOW & S. K. BRADFORD.
CARBURETER FOR INTERNAL COMBUSTION ENGINES.

1,049,088. Patented Dec. 31, 1912.



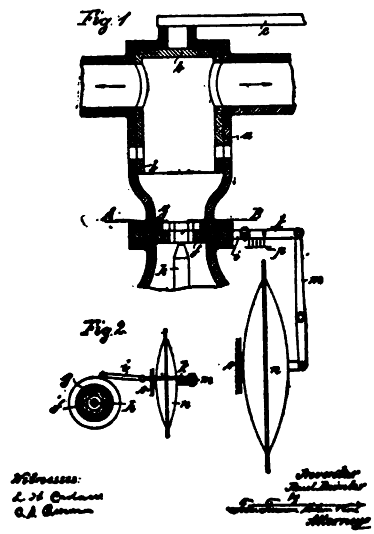
W. BARSTOW & S. K. BRADFORD.
CARBURETER FOR INTERNAL COMBUSTION ENGINES.

1,049,088. Patented Dec. 31, 1912.



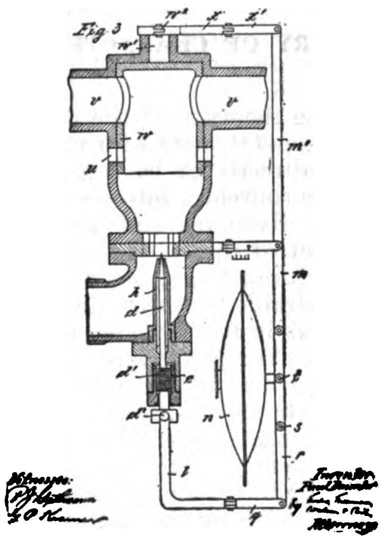
P. DAIMLER.
CARBURETER.

1,098,783. Patented June 2, 1914.



P. DAIMLER.
CARBURETER.

1,098,783. Patented June 2, 1914.



these actuated by the exhaust is shown on page 437 (1,133,872, Mar. 30, 1915, Maness), operates the fuel valve by the elongation of a metal rod close to the exhaust pipe, and another, page 438 (1,149,743, Aug. 10, 1915, England), uses the elongation of a tube heated by the jacket water. Both forms are directly applicable only to those classes of carburetors that have an otherwise fixed fuel inlet.

A similar effect is sought by thermostatic control of a separate secondary air valve which is closed when the air or the engine is cold so as to enrich the charge, and which opens when the temperature at the thermostat rises, diluting the charge and compensating for an over-rich mixture from the carburetor. Use is made of a thin metal bending strip on page 438 (1,189,786, July 4, 1916, Byrnes), in one case operated by exhaust and in another by the air temperature, associated with various valve forms.

Subclass 15.2, barometric controls.—A barometric diaphragm, consisting of two flexible metal sheets, joined at the edges, inclosing and forming a vacuum chamber, is fixed to the carburetor casing on one side and to the fuel needle on the other, on page 439. (1,049,038, Dec. 31, 1912, Barstow & Bradford.) Any changes of barometric pressure are compensated for by movement of the fuel needle. Incidentally there is also provided a float and float-chamber form, intended to work equally well at any angle of inclination of the carburetor from the vertical within a fairly considerable range. This form is, of course, applicable only to carburetors with otherwise fixed fuel inlets. Another form, shown on page 439 (1,098,783, June 2, 1914, Daimler), is adapted to be inserted in the train of linkage between a fuel needle and its normal source of adjustment for regulation with air flow, by moving the fulcrum of one otherwise fixed point of a lever in the linkage.

SUMMARY OF CHARACTERISTICS OF NEW CLASSES AND CONCLUSIONS ON TYPE.

On the theory that the definition of a class or subclass of carburetors is a statement of a principle of construction or functional operation directly or by implication, it would seem to be possible to divide carburetors into good, fair, and bad groups by the class and subclass divisions, and very desirable to do so as the first broad treatment of the subject of design before undertaking any analysis of structural details or dimensions. Unfortunately, however, this very desirable prospect can not be fulfilled, because any classification basis that is feasible and practical must be based primarily on the more quickly recognized features of the appliance, and these are always structural arrangments from which principles of operation must be discovered by later analysis, and the only principles of construction that can enter into class definitions are those of structural arrangement. In all cases proportions of parts and at least relative if not absolute dimensions play as important a part in the separation of the good from the bad as does the general arrangement or grouping of the elements of construction, so much, in fact, as to be responsible for one of the greatest sources of difficulty in making the class distinctions themselves. There may, for example, be two air inlets located so that both air streams act as one, and the case should

therefore be classed with those characterized structurally as having one. Again, even though the two air streams act differently, one, for example, acting as primary air passing the fuel jet and the other as secondary entering beyond it, still several possible class interpretations are possible because either the primary or the air inlets may be so small as to be negligible, in which case two class interpretations result: First, that of all air entering beyond the jet; and, second, that of all air passing the jet in addition to the third where both air streams exert a measurably equal influence. Moreover, the small air inlet while so small as to be negligible when entering the mixing chamber directly may, on the contrary, be most potent in its influence, if, for example, it passes through the top of the float chamber or into the fuel passage, either case representing a most important and different class characterized by either of these two important means of compensation.

In spite of such conditions as these, it is possible to draw some very valuable class distinctions on the basis of possibilities of suitable automatic control of proportionality as the flow rates change, but not by the simple process of branding any one class as good or bad without qualification. Even this sort of division is most useful because it points clearly the direction that efforts should follow to improve and perfect the carburetor, and serving to divert time and money from the losses that must inevitably follow by their expenditure on the less promising types.

Of the 15 classes here established, not a single one can be wholly approved, and only one, class No. 1, wholly condemned, but naturally the subclasses of each general class, 61 in all, can be judged better than is possible for the general classes themselves. Even these, it has been found, are best judged as bad to fair, or fair to good, rather than good, fair or bad alone, except for one small set that is clearly bad. This set includes those subclasses that consist of the single fixed fuel and air inlets without any compensation whatever, and designated as subclasses 1.1, 1.2, 1.3, 1.4, 3.1, 3.2, and 3.3, 7 in all. Removing these 7 there remain of the 61 subclasses 54 that merit the broader judgment. Of these the following 20 are designated as bad to fair, and constitute the group that merits the lesser consideration, as being unequal to the rest in proportionality possibilities for engines operating at varying speeds under variable loads: Subclasses 5.1, 5.2, 6.1, 6.2, 6.3, 7.1, 7.2, 8.1, 8.3, 8.5, 9.2, 9.4, 11.1, 12.1, 12.2, 12.3, 12.4, 13.1, 13.2, 13.4. All of these subclasses are provided with proportionality compensation of some kind but considered not as adequate or suitable as that of the following 29, designated as fair to good: Subclasses 3.4, 3.5, 4.1, 5.3, 6.4, 6.5, 6.6, 7.3, 7.4, 7.5, 8.2, 8.4, 8.6, 9.1, 9.3, 10.1, 10.2, 10.3, 10.4, 10.5, 10.6, 11.2, 11.3, 12.5, 12.6, 12.7, 13.3, 13.5, 13.6. These two sets, aggregating 49 subclasses of double judgments with the previously noted 7 single judgment group, account for 56 of the total of 61 subclasses.

Of the remaining five subclasses, three—9.5, 14.1, and 14.2—are so broad in definition as to make a class judgment impossible or what is the same thing, to warrant a triple judgment of bad, fair, or good, depending on the details of each case. The remaining two subclasses—15.1 and 15.2—concerned with thermostatic and barometric control do not admit of a judgment on the same basis as the others be-

cause this sort of compensation to be useful must be added to but can not serve as a substitute for compensation for flow rate proportionality influences.

All the general classes with the exception of class 1, which includes only incompensated cases, and class 15, which is concerned only with thermostatic and barometric supplemental compensation, are not to be judged as good, fair, or bad as a class because each includes some variation of from that may be classed many of the three ways.

For the variable speed, variable load engine, the carburetor that consists merely of two passages, one for air and one for fuel, fixed in both area and position, is of no value whatever, because no matter what the form or relative position of the passages, the flow of the fuel can not be made to follow in constant ratio that of the air. Depending on the fuel supply which may be under a constant positive liquid head or be aspirated against a constant negative liquid head, and on the position of the fuel jet in the air passage which may be located to be influenced by an air entrance resistance vacuum or not, and by a positive or negative air velocity head vacuum, the fuel flow may increase faster than the air flow increases or slower, but it can not be made to increase at the same rate as the air. This is due to the nature of the flow laws of air and liquids through the various forms of passages of such dimensions as are suitable for carburetors, and it does not appear to be within the range of mechanical ingenuity or the skill of designers to overcome this condition except by departing from the simple fixed inlets or the constant fuel head, by introducing a correcting variable; in short, by providing a proper sort and amount of compensation.

The uncompensated cases thus eliminated from consideration for variable speed, variable load engines, or engines in which the flow is as much determined by engine-resting torque or speed as by throttle position includes those of subclasses 1.1, 1.2, 1.3, and 1.4, having periodic fuel valves with or without periodic air valves that open each suction stroke, but which present fixed areas for flow when open whether the fuel valve is operated mechanically from the valve gear (1.1), or is opened by the lifting of an automatic air valve with the fuel inlet in the seat (1.2), or opened by the movement of an automatic air valve in front of the fuel valve (1.3), all with a single air inlet, or any of these arrangements with a second independent air inlet (1.4). There are also included in the rejected uncompensated cases those of subclasses 3.1, 3.2, and 3.3, all having plain single fixed air and fuel inlets with reference to area and position, no matter how arranged, whether the fuel inlet is at a restricted air throat (3.1), with or without air-directing vanes, baffles, or guides (3.2), or provided with rotating spreading and mixing surfaces (3.3). It must be understood that an air or a fuel inlet is fixed when its area does not change with flow; it may have manually adjustable valves for changing a flow area, which, however, once so set remains fixed, no matter how the flow rate may change with engine speed and throttle variations.

Designers must, therefore, concentrate attention on the problem or compensation and develop, first, various schemes or qualitative means of compensation and, second, apply to each of these the physical laws belonging to or characteristic of it as the quantitative and

final means of compensation to secure properly proportioning flow carburetors correct in capacity for a given engine. Of course, in every case there must be available full and complete data (*a*) on the flow laws for every kind and size of both air and fuel passage, relating quantity to vacuum; (*b*) on the vacuum at every point in an air passage where a fuel nozzle might be located and its law of change with air flow to fix the relation between air flow and fuel flow through this common vacuum. Without such data, now pretty generally lacking, the amount of compensation needed can not be known without experimental trial, which, of course, while one means of solution, is not a proper one, and certainly is not a means that can be characterized as design.

So far, improvement of carburetors has followed almost entirely the qualitative line, attention having been concentrated on compensating schemes almost to the exclusion of the quantitative determination of flow or proportionality laws to reduce to tabular, graphic, or algebraic form either the amount of compensation required or the degree of success attained with what has been provided by cut-and-try empiric methods. Now that a reasonable number of compensating means has been disclosed, any one of which would seem to be adequate if properly applied, the time seems ripe for reducing to the quantitative basis the various flow laws of each element and for the combination of such elements that make up a carburetor.

Compensating means for proportioning flow carburetors are of three general types, and there are several specific classes of each type now available. These three types are named, first, flow area; second, fuel head; and, third, combined flow area and fuel head.

Compensation by flow area includes all those arrangements in which either the air-flow area or the fuel-flow area, or both, is varied with the flow rate automatically in such a way as to correct for departures from constancy of proportionality; reducing the fuel or increasing the air-flow area whenever fuel is in excess by just the right amount to reduce the excess to zero, and the opposite when air is in excess. This may be done by providing (*a*) a graduating fuel-inlet valve in connection with a fixed-air inlet; (*b*) a graduating air-inlet valve in connection with a fixed-fuel inlet; (*c*) graduating valves on both fuel and air inlets; (*d*) a multiplicity of fixed-fuel inlets coming into action successively in connection with a similar multiplicity of fixed-air passages; (*e*) a multiplicity of fixed-fuel inlets coming into action successively in connection with a single air passage provided with a compensating regulating valve. In all cases the flow-area change should be directly related to and controlled by the flow rate itself.

Compensation by fuel head includes all those arrangements in which the net fuel-flow head is changed from the value it would have if the fuel nozzle were fixed at a given point in the air passage where the vacuum is directly related to and determined by the air-flow rate, and if at the same time the fuel supply were taken from a constant-level chamber with a constant-surface pressure. This end may be attained by (*f*) changing the position of a fixed area fuel nozzle in a fixed area tapered air passage, or the position of the air passage around the fuel nozzle, used in connection with a constant level, constant pressure fuel-supply chamber; (*g*) admitting air to the

fuel passage at a point between the fuel-supply chamber and the fuel nozzle, to reduce the vacuum there and reduce the fuel flow, used in connection with fixed flow areas and otherwise constant fuel-supply heads; (*h*) reducing the pressure in the constant-level fuel-supply chamber, in connection with fixed flow areas; (*i*) combinations of changes of nozzle position in the air passage, float-chamber pressure, and of air admission to fuel passages. Again, it is assumed that these changes take place automatically to vary with the flow rate.

Compensation by combined flow area and fuel head, includes all of those arrangements in which the flow area and the fuel head vary at the same time. This may be done by (*j*) associating valved fuel and air inlets, (*a*), (*b*), and (*c*), with head control by nozzle position (*f*) mixed flow (*g*); or with float chamber pressure (*h*); or with their combinations (*i*); but there are two special cases of multiplicity of fixed fuel inlets coming into action successively on which the head varies at the same time. These are (*k*) the single or multiple stand pipe having fixed holes at different vertical heights above a constant-level, constant-pressure fuel-supply chamber, fixed in an air passage, so that increase of vacuum brings higher holes into action thereby increasing the flow area at a point of different vacuum than that of the lower holes; and (*l*) the tilting chamber with a series of fuel holes or nozzles, the fuel head on which changes as they are depressed with reference to the constant-level, constant-pressure fuel-supply chamber, while at the same time they move in the air passage to regions of different vacuum due to position rather than height.

In general, only one of the simple direct means of compensation is necessary, and there is not only no good end attained by combining in one carburetor more than one compensation acting at the same time, but there is danger of positive harm because one may operate in opposition to the other over a part or the whole of the flow range and thereby neutralize the other, the over-all effect being no better than if no compensation at all were provided and the structure much more complicated. Those developments that have been made by the cut-and-try method are most likely to have double or triple compensation, because the first means being improperly worked out is found inadequate and another is added by the experimenter without due effort to perfect the first means. This is not always the case, however, and there are possibilities of structural arrangement that naturally tend to combine the different means of compensation and to produce not only the desired simple structure but suitable compensation as well. Such cases as this are the exception rather than the rule and should not be regarded as an argument in favor of multiple compensation which should be used only when there is a good clear advantage to be derived thereby, and when positive means are provided to prevent any possibility of interference and neutralization of one by the other.

One excellent example of this is found in the use of an air inlet valve with a fuel inlet valve where the fuel valve alone could provide adequate compensation. Here the air valve addition in the automatic form provides not only a suitable and proper actuating means for the fuel valve, but in addition it directly contributes to the prevention of a high vacuum in the mixing chamber so undesirable

from the standpoint of maximum engine capacity which requires that the fuel charge have the highest possible absolute pressure.

Those subclasses that have some sort of compensation but inadequate or improperly applied, are judged as bad to fair, while those in which the compensation is proper in kind are judged as fair to good, depending on the degree to which use is made of the compensation possibilities, and finally the triple judgment is applied to those subclasses in which the definition may include the whole range from no compensation at all to complete and satisfactory correction of wrong proportions.

The judgment of bad to fair is applied to the following compensated subclasses because the compensation is inadequate or wrongly related to flow.

(A) Compensation wrongly related to flow because the throttle is the actuating element, and throttle position is not the determining factor in fixing the rate of flow:

I. Throttle actuates the fuel regulating valve. Subclass 11.1, single or multiple fuel inlet with single or multiple fixed air inlet; and subclass 12.4 single fixed fuel inlet, single air inlet with automatic valve.

II. Throttle actuates the air regulating valve or is itself the air valve. Subclass 7.1, single fixed fuel inlet between single air inlet valve and throttle; subclass 7.2, single fixed fuel inlet in front of single air inlet valve acting as throttle; subclass 8.1, single fixed fuel inlet fixed primary and throttle controlled secondary air; subclass 8.3, single fixed fuel inlet, automatic primary and throttle controlled secondary air; subclass 8.5, single fixed fuel inlet, primary and secondary air, both throttle controlled.

III. Throttle actuates both the fuel and the air regulating valves or, acting as the air regulating valve, actuates the fuel valve. Subclass 12.1, single fuel inlet beyond single air valve acting as throttle; subclass 12.2, single fuel inlet between single air valve and throttle; subclass 12.3, single fuel inlet at or in front of air valve acting as throttle; subclass 13.1, single fuel inlet, fixed primary and throttle controlled secondary air; subclass 13.2, single fuel inlet, throttle controlled primary and secondary air; subclass 13.4, single fuel inlet, fixed primary and automatic secondary air; part of subclasses 14.1 and 14.2, including all cases of throttle control.

IV. Throttle control of succession of multiple fixed fuel jets, in single or separate air passages. Subclass 6.2, more than two fixed fuel inlets, each in separate fixed air inlet; subclass 9.2, more than two fixed fuel inlets in single air passage; part of subclass 9.5, the tilting chamber, with multiple fuel nozzles, if tilted by the throttle or air valve, acting as throttle.

(B) Compensation wrongly related to flow because discontinuous. Two point compensation instead of continuous or multiple point by successive or alternate action of two fuel inlets, each separately adjustable for one different flow rate at the ends of the range, whether the succession be controlled by the throttle position or the vacuum in one or separate air passages. Subclass 5.1, one fixed main fuel inlet and one fixed auxiliarly high-speed jet, single fixed air inlet; subclass 5.2, one fixed main fuel inlet and one fixed auxiliary low-

speed or idling jet, single fixed air inlet; subclass 6.1, double carburetor with two fixed fuel inlets in separate fixed air passages, succession controlled by throttle; subclass 6.3, double carburetor with two fixed fuel inlets in separate fixed air passages, succession controlled by vacuum; subclass 9.4, one fixed main fuel inlet and one fixed auxiliary low-speed or idling jet in single variable air passage, vacuum or throttle succession.

The judgment of fair to good is applied to the following subclasses because each provides compensation of a proper kind, which may or may not be adequate in degree. The several subclasses are grouped according to the type of compensation that is the controlling one, if two or more are provided, as is the case in some instances.

(A) Automatically varying relation of fuel nozzle to air-passage throat. Subclass 3.4, throat moves past fixed nozzle, or nozzle moves in fixed throat, without changing fuel or air inlet area, movement controlled by the vacuum corresponding to the air-flow rate.

(B) Mixed flow fuel head control by admission of air to the fuel passage to vary the fuel flow head on the delivery side, the amount of mixed flow and air and its compensating effect controlled by the vacuum corresponding to the air-flow rate. Subclass 4.1, single fixed fuel inlet, single fixed main air inlet, with auxiliary mixed flow air inlet acting continuously perintermittently; subclass 6.5, multiple fixed fuel and air inlets, at least one air inlet entering at least one of the fuel passages, and acting continuously or intermittently; subclass 8.6, single fixed fuel inlet, multiple variable air inlets, at least one of the air inlets entering the fuel passage and acting continuously or intermittently; subclass 11.3, single or multiple fixed air inlets, at least one of the air inlets entering at least one of the fuel passages and acting continuously or intermittently.

(C) Float-chamber pressure control by passing air through the top of the float chamber to the mixing chamber to vary the fuel flow head on the supply side, the compensating effect controlled by the vacuum corresponding to the flow rate. Subclass 3.5, single fixed fuel and air inlets, with small auxiliay air flow through top of float chamber; subclass 7.5, single fixed fuel and single variable air inlets with small auxiliary air flow through top of float chamber; subclass 12.7, single variable fuel and air inlets, with small auxiliary air flow through top of float chamber.

(D) Fuel standpipe double control of fuel head and fuel flow area, the head on the successive holes and the number and area of holes controlled by the vacuum corresponding to the air-flow rate. The fuel inlets are all described as multiple fixed and associated with the following elements: Subclass 5.3, single fixed air inlet; subclass 6.6, multiple fixed air inlets; subclass 9.3, single variable air inlet; subclass 10.5, multiple fuel nozzles if tilted by vacuum or air flow.

(E) An inlet area, varied by regulating valve with single fixed fuel inlet, the valve controlled by the vacuum corresponding to air-flow rate or by the flow rate itself directly. Subclass 7.3, single air inlet, with automatic valve, fuel entering beyond; subclass 7.4, single air inlet, with automatic valve, fuel entering at point swept by entering air; subclass 8.2, fixed primary and automatic valved secondary air inlets; subclass 8.4, primary and secondary air inlets, both automatic valved.

(F) Air inlet area varied by regulating valve with multiple fixed fuel inlets in one or in separate air passage, the active area of each, and the succession of which, are controlled by a valve actuated by the vacuum corresponding to the air flow rate or by the air flow itself directly. Subclass 6.4, more than two fixed fuel inlets, each in a separate fuel passage and fixed except for the single automatic valve; subclass 9.1, multiple fixed fuel inlets in single air passage brought into action successively as the automatic valve changes the air flow area.

(G) Fuel inlet area varied by regulating valve, with single or multiple fixed air inlets, automatically with the air flow rate. Subclass 11.2, single fuel inlet, fuel valve actuated by the vacuum corresponding to the air flow rate or by the air flow itself without changing the air inlet area.

(H) Fuel and air inlet areas both varied automatically with the air flow rate, the fuel valve acutated by the automatic air valve, or the air and fuel valves independently actuated by the vacuum corresponding to the air flow rate or by the air flow itself directly. Subclass 12.5, single fuel and air inlet, fuel valve controlled by automatic air valve; subclass 12.6, single fuel and air inlet, the fuel inlet valve controlled directly by the vacuum or the air flow and the air entering through a mechanical or an air automatic valve; subclass 13.3, single fuel valve controlled directly by the vacuum or air flow with fixed primary and variable secondary air; subclass 13.3 single fuel inlet, fixed primary and automatic valved secondary air actuating the fuel valve; subclass 13.6, single fuel inlet, automatic primary and secondary air valves, one or both controlling the fuel valve; part of subclasses 14.1, and 14.2 including all those cases where the fuel and air control is automatic and not by throttle.

(I) Successive point fuel-area control with regular variation of air area automatically. Subclass 10.1, two fuel inlets, one fixed main jet, and one fixed auxiliary high-speed jet brought into action at high-flow rates by the vacuum or by the action of the automatic secondary air valve, with fixed primary and automatic secondary air inlets; subclass 10.2, two fuel inlets, one fixed main, and one fixed auxiliary low-speed or idling jet brought into action by the vacuum above the throttle or by the throttle closure, with fixed primary and automatic secondary air-inlets; subclasses 10.3 and 10.4, two or more fuel inlets each with a separate air passage receiving all or part of the air through an automatic valve, with or without a common automatic secondary air valve, the succession of action of the several chambers being controlled by the vacuum, respectively.

The triple judgment, or no judgment at all, applying to all the general classes except the first, which is rejected as uncompensated, also applies to the following subclasses, with the division and limitation noted in each case. The first of these is subclass 9.5, concerned with fuel-head and fuel-flow area control simultaneously, somewhat similar to the standpipe idea, but here brought into action by tilting a multijet chamber. If the tilting be accomplished by the vacuum or air flow automatically, then these cases belong in the fair to good group (D); but, on the other hand, if, as is more often the case, the tilting be done by the throttle or by an air valve acting as throttle,

then they fall in the bad to fair group (A). Similarly, subclass 14.1, two fuel inlets, one fixed and the other with a regulating valve for high speed in connection with single or multiple variable air, belongs with the fair to good group (H), if the fuel valve is controlled by the vacuum or flow, even if the air valve is throttle controlled, and more especially so if it is automatic and itself controls the fuel; whereas, on the other hand, if the fuel valve is throttle controlled even with an automatic air valve, and especially with a throttle-controlled or throttle-acting air valve, the case belongs with the bad to fair group (A). Again, those multiple carburetors each unit of which contains a variable fuel and variable air element, and to which may be added a common secondary air valve, belong to the fair to good group (H), or to the bad to fair group (A), no matter whether the succession or progression is controlled automatically or by the throttle, depending on the nature of the control of the separate unit fuel and air valves, to the former if automatic, to the latter if connected to throttle.

Assuming that by this analysis a series of typical forms and arrangements of compensating carburetors, classed as fair to good, involving a set of generally available compensating means that can be used single, or several of which can be jointly employed to coact in a single carburetor, provided interference and neutralization of their influences is prevented, it is necessary to establish some basis of distinguishing the fair from the good, or more directly to specify the elements or conditions that shall yield a good rather than merely a fair result. This is the quantitative side of the question and generally speaking is not the sort of thing that can be put into general language, but requires first the establishment of a large quantity of experimental data on flow laws or the relation of the vacuum at a point in an air passage that might be occupied by a fuel jet to the flow law of the air passage, all reduced to algebraic or at least to graphic and tabular form.

It is, however, possible to draw a few general conclusions of some value as guides. In the first place, it must be pointed out that all the different typical means of compensation that belong to the general class of varying the fuel flow head from what it would be with a fuel nozzle in a fixed position in the air passage and a constant level fuel supply at constant surface pressure are themselves dependent on flow laws. Therefore, to apply such compensation as is derivable from mixed flow float chamber pressure control, and fuel standpipes, the flow laws of the uncompensated passages must not only be known, but also the laws of flow for the compensating passages themselves. The same thing is true for the compensation by variable relation of the fuel-jet position in the air-passage throat, because unless the vacuum at every point of the throat is known for any flow rate, it is impossible to determine how much movement will be needed to compensate for the incorrect proportions that result from a fixed position. Of course, as has been pointed out before, the desired result may be attained by cut and try methods, but it is more than likely that such methods will produce only a measure of what is possible by the scientific method, though it is possible that patience and good luck may make data unnecessary. Of the three fixed pas-

sage compensating means, that by mixed flow is by all odds the best, the standpipe suffering interference by inertia and requiring excessively minute orifices when the aggregate of many shall equal in area a single one that is itself pretty small. The float chamber pressure control is next in order of promise, but is subject to interference by leaks, dirt, and splashing when under vibration or when tilted.

The next conclusion worthy of notice is that all these compensations by fuel-flow head control are applicable to fixed passageways which once established need no further adjustment except as may be required to correct for fuel and air density and fuel viscosity changes, the function of subclasses 15.1 and 15.2, though, of course, these can not be expected to correct for a change in the character of the fuel when a more viscous is substituted for a less viscous kind. This is one limitation of the fixed fuel passage carburetor, and is an offset to its excellent feature of nonadjustability, a matter of greater importance the less the skill of the operator. Perhaps a more serious drawback is the rate at which the vacuum increases and the mixture density decreases, with increase of flow rate, when the air passage is one of fixed area. It is clear that if at low speeds the air-inlet area is small enough to establish a reliably steady fluel flow, then at the maximum flow rate corresponding to the maximum speed and load of the engine the mixture vacuum will be quite high and the capacity of the engine lower than it would be if the air-inlet area increased with flow rate, other things being equal.

This is the principal argument in favor of the automatic valved air inlet, which has a good deal to recommend it otherwise, and no very serious disadvantages, if intelligently worked out. No automatic valve that requires a variable load derived from a spring, the resistance of which varies with its distortion, can be approved, nor can any loading linkage or cam arrangements in which wear or dirt may affect the motion or the loading. Any possibility of this sort means an unexpected and perhaps disastrous interference with the compensation and, therefore, with the working of the engine. There can be no corresponding objection to the use of automatic air valves that are gravity-loaded without springs or that have spring loads that are constant—that is, that do not vary with the entire range or distortion permitted, a constant load spring being precisely equivalent to a gravity load except for the item of inertia which is less. Another similar loading that is possible is the constant buoyancy of a float constantly submerged in a liquid chamber. With such loading, moreover, the air valve can be relied upon for movement over its whole range with but little, if any, change of vacuum and, therefore, becomes a means of securing a mixture at the maximum possible absolute pressure without the use of boosting fans, blowers, or pumps.

Only such forms of automatic air valve should be used as are not subject to sticking, a defect of this class of appliance, because the actuating forces are feeble. Certainly the form should be such that wear shall not interfere with the action by creating a leak path for the air. This points to centrally guided valves of the circumferential seating form rather than to piston or sleeve forms. With such slight vacuum as develops with a constant load automatic valve the

fuel flow required can be maintained only by the use of a fuel valve the area through or past which must vary with that through or past the air valve, and as such air valves are themselves equivalent to air meters, their movement indicating directly or indirectly the air flow volume, this same movement seems a most logical actuating means of the needed fuel valve. Assuming that a connection of this sort is to be used, it must be pointed out that the relative areas can be established experimentally with absolute precision without first establishing the flow laws for the air and fuel passages, because the shape of the air valve and its seat or guiding walls may be selected and the proper form of needle established by testing the proportionality over the flow range and cutting the needle or its seat to correct for deficiencies at any point. The inverse and easier method may, however, be substituted, that of selecting a needle form that is easily made with precision, and experimentally shaping the air valve or its seat. The latter is preferable because of the larger dimensions to be adjusted and the lesser consequence of shop error.

In this analysis the throttle-controlled compensations have been rejected in favor of those that are automatically controlled by the air-flow conditions, on the assumption that the throttle position is not a prime variable in the rate of flow in carburetors. This is certainly justifiable in the case of engines of the automobile class where resisting torque is widely variable, and therefore engine speed and carburetor flow rate also under any given throttle position. It is true to a lesser degree of engines driving screw propellers whether they be in water or in air. If the propeller for a given engine were to be always the same, and if it were to rotate in water or air always in the same state of density and of motion as to amount and direction, then it would not be true, because the engine speed and the carburetor flow rate would be controlled by the throttle alone. In view, however, of the fact that propeller-rotating resistances do vary at a given speed, especially when rotating in air, and that for a given driving torque the rotative speed will also vary, then the throttle position ceases to be a prime variable, though the situation is not so bad as with the land vehicle. That carburetors can be designed to meet the worst sort of independence of flow rate with respect to throttle position, warrants the conclusion that this sort must be approved even for the propeller service over the others that depend for their accuracy of proportioning on the assumption that flow rate is fixed by throttle position alone, and always will be no matter when, where, or how used.

All variations in flow rate through a carburetor having any sort of throttle-controlled compensation that take place at any fixed throttle position, due to changes in resisting torque mainly, though to some extent also to spark angle, must affect mixture proportions as if the throttle-actuated compensator were absent. This would most seriously disturb those classes in which the only compensation provided were throttle controlled, and less seriously those in which the throttle-controlled compensator supplements another compensator that is automatically actuated by flow conditions directly. The result would be least serious in boat and aero engines and most in land transportation machines, like the automobile, tractor, and railroad engines.

Even if it should be found in the case of propeller-drive engines for aero and marine work that throttle-controlled compensators did not seriously disturb proportionality in the carburetor, it is nevertheless advisable to use even for them those classes of carburetors having automatic compensation, controlled directly by the flow rate, unless it could be shown that more would be lost than gained by so doing. One condition that might be cited as an example justifying such a decision is that of sticking versus nonsticking of a moving part, which in the preferred group of carburetors is automatically actuated by the flow rate, but in the other is manually controlled. Even the most perfect carburetor from the proportionality standpoint might properly be described in favor of a less accurate instrument with a throttle-actuated compensator, if in the former case the movement of an air valve, for example, were irregular and jerky, until such time as improved mechanical design could remedy the defect and insure reliability of action.

REPORT No. 11.

PART V.

FLOW LAWS FOR GASES AND LIQUIDS, WITH SPECIAL REFERENCE TO AIR AND GASOLINE IN PASSAGES FOUND IN CARBURETORS, WITH COEFFICIENTS OR TEST DATA TO BE FOUND IN THE LITERATURE OF THE SUBJECT.

By Charles E. Lucke.

(A) FORMULAE FOR THE FLOW OF FLUIDS, BASED ON HYDRAULIC AND THERMODYNAMIC LAWS.

1. *Flow of fluids—General conditions.*—Before giving coefficients for special cases, it seems desirable to review briefly the general laws for the flow of gases and liquids.

The simplest case is that of a fluid, gaseous or liquid, passing through a straight pipe of unvarying cross section. If all the particles of the fluid move in straight paths parallel to the axis of the pipe, and with the same velocity, the quantity by volume passing a given cross section in unit time is $Q=u.\ A$, where u is the velocity of any particle and A the area of the cross section. This, however, does not represent the actual case. Close to the wall will be a dead layer of fluid clinging to the pipe and having no velocity. Next to this layer will be a slowly moving layer and the velocities of these thin layers will increase toward the center of the pipe, where the maximum velocity is found. In general, then, if the quantity is to be determined by velocity measurements, as, for instance, by the use of a Pitot tube, the velocity will have to be determined at a number of points representing equal areas and the actual mean velocity found. In that case the equation still is $Q=u_m.\ A$, where u_m is the mean velocity. In general, however, the equation will have to be—

$$Q=\int a.du \qquad (1)$$

Experience has shown that even the case in which friction is considered does not represent actual conditions except at the very lowest velocities, i. e., in general the individual particles do not move in straight-line parallel paths. Instead the flow is more or less turbulent. This is due to viscosity, which varies between the widest limits among different fluids, and even for any one fluid when the temperature changes. Even in the case of the lightest gases viscosity plays a certain part. Whenever the difference in velocity between two adjacent layers becomes great enough, depending on

the kind and condition of the fluid, the two layers will actually separate, and turbulent flow is the result.

If the cross section of the pipe or channel varies, the mean velocity can not remain constant. For continuous flow the weight passing any section in unit time must be constant, and if $\frac{W}{t}$ represents this quantity and u_1, $A_1 w_1$ represent the mean velocity, area, and specific weight, respectively, at section 1, and using similar subscripts for other sections,

$$\frac{W}{t} = A_1 u_1 w_1 = A_2 u_2 w_2 = A_n u_n w_n \tag{2}$$

For liquids the specific weight is practically constant and the equation simplifies to

$$A_1 u_1 = A_2 u_2 = A_n u_n \tag{2a}$$

Thus for liquids the areas are inversely proportional to the velocities, and for very small pressure changes this also applies to gases and vapors with sufficient accuracy.

2. *Flow of gases—General case—Theoretical flow rate.*—Not only the weight passing any cross section in unit time must be constant, but also, according to the law of the conservation of energy, the energy per unit mass at one point of the pipe must be equal to the energy per unit mass of the stuff at any other point in the pipe if there is no heat interchange with the surrounding medium. This is expressed by the equation

$$I_1 + p_1 v_1 + \frac{u_1^2}{2g} = I_2 + p_2 v_2 + \frac{u_2^2}{2g} = \text{Constant} \tag{3}$$

in which $I_{1.2}$ = internal energy per pound of fluid
$p_{1.2}$ = static pressure in pounds per square foot abs.
$v_{1.2}$ = specific volume in cubic feet per pound
$u_{1.2}$ = velocity in feet per second
g = gravitational acceleration
= 32.16 feet per second per second.

This assumes the centers of sections 1 and 2 to be on the same level, i. e., a horizontal pipe. p_1 is the pressure which would be indicated on a gauge floating in the stream. It may be determined by drilling a hole at right angles to the wall of the pipe and attaching a manometer or gauge, but this will give the true static pressure only at low velocities. At higher velocities the aspirating effect lowers the readings.

Transposing

$$\frac{u_2^2}{2g} - \frac{u_1^2}{2g} = I_1 + p_1 v_1 - I_2 - p_2 v_2 \tag{3a}$$

assuming adiabatic conditions,

$$I_1 - I_2 = \frac{p_1 v_1 - p_2 v_2}{n-1} \text{ where } n = \frac{C_p}{C_v}$$

substituting and simplyfying,

$$\frac{u_2^2}{2g}-\frac{u_1^2}{2g}=\frac{n}{n-1}\ (p_1v_1-p_2v_2)$$

but,

$$p_1v_1^n=p_2v_2^n$$

hence,

$$\frac{u_2^2}{2g}-\frac{u_1^2}{2g}=\frac{n}{n-1}\ p_1v_1\left[1-\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}\right] \tag{4}$$

For continuous flow from equation (2),

$$W_{sec}=A_1\frac{u_1}{v_1}=\frac{A_2u_2}{v_2}=A_2\frac{u^2}{v_1}\left(\frac{p_2}{p_1}\right)^{1/n}$$

hence,

$$u_1=u_2\cdot\frac{A_2}{A_1}\cdot\left(\frac{p_2}{p_1}\right)^{1/n} \tag{5}$$

substituting in equation (4)

$$u_2=\sqrt{2g\frac{n}{n-1}\cdot p_1v_1\cdot\left[\frac{1-\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}}{1-\left(\frac{A_2}{A_1}\right)^2\left(\frac{p_2}{p_1}\right)^{\frac{2}{n}}}\right]} \tag{6}$$

and

$$W_{sec}=A_2\left(\frac{p_2}{p_1}\right)^{1/n}\cdot\sqrt{2g\frac{n}{n-1}\cdot\frac{p_1}{v_1}\cdot\left[\frac{1-\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}}{1-\left(\frac{A_2}{A_1}\right)^2\left(\frac{p_2}{p_1}\right)^{\frac{2}{n}}}\right]} \tag{7}$$

This equation is based on the assumption of nonturbulent flow and neglects heat flow through the pipe walls. When it is used for Venturi meter tubes, p_1 is the upstream pressure and p_2 the pressure at the "throat." v_1 is the reciprocal of the density at upstream pressure and n for air is 1.403.

3. *Flow of gases—Theoretical flow rate for small pressure differences.*—In equation (3*a*) the right-hand member is an expression of the work during the change from condition (p_1, v_1) to (p_2, p_2). Graphically it is represented by the indicator card of an ideal air engine or air compressor, with no clearance and adiabatic expansion or compression. Now when the pressure range is very small, this diagram becomes practically a rectangle, i. e., v_2 is very nearly equal to v_1 so that equation (3*a*), is simplified and reads,

$$\frac{u_2^2}{2g}-\frac{u_1^2}{2g}=p_1v-p_2v \tag{8}$$

$$=\frac{p_1}{w}-\frac{p_2}{w}\text{ where } w=\text{mean density.}$$

It can be shown that the error of this approximation is equal to $\frac{1}{2.8} \cdot \frac{\text{Pressure range}}{\text{pressure}}$ for air, or if the error is not to exceed 1 per cent the pressure range must not exceed 2.8 per cent of the pressure. Thus for work near atmospheric pressure the pressure range must not exceed $0.028 \times 408 = 11.4$ inches of water for a maximum error of 1 per cent, or 22.8 inches if 2 per cent are allowed. It is well to know exactly what error to expect when using an approximation and not simply to speak about "small pressure drops" without specifying.

4. *Flow of gases through orifices—Theoretical flow rates—General case—Critical pressure ratio.*—When a gas flows from a large vessel through any kind of an orifice into the atmosphere or into another vessel, the pressure in the vessel p_1 being greater than the pressure outside, p_2, the general equations (6) and (7) of course apply, so long as adiabatic flow is assumed, but they may be simplified, since the term $[1-\left(\frac{A_2}{A_1}\right)_2\left(\frac{p_2}{p_1}\right)^{2/n}$ becomes very nearly equal to one and may be neglected. In the case of the flow from the atmosphere into the carburetor, for instance u_1 becomes zero and the above term does not exist. In other cases the error will have to be determined.

With the assumption then that u_2 is very large compared with u_1, equation (6) is transformed into

$$u = 2g.\frac{n}{n-1}.p_1v_1.[1-\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} \tag{9}$$

where u is the velocity of efflux from the orifice and p_2 the pressure at the smallest cross section of the orifice which for the present is assumed to be a hole in a thin plate or a short converging nozzle, so that p_2 is equal to the pressure of the medium into which discharge takes place. The latter statement, however, is not generally true as will be seen below.

Equation (7) takes this form:

$$W_{sec} = A.\left(\frac{p_2}{p_1}\right)^{1/n}\sqrt{2g.\frac{n}{n-1}.\frac{p_1}{v_1}\left[1-\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}\right]} \tag{10}$$

or

$$W_{sec} = A\sqrt{2g\frac{n}{n-1}\cdot\frac{p_1}{v_1}\left[\left(\frac{p_2}{p_1}\right)^{2/n}-\left(\frac{p_2}{p_1}\right)^{\frac{n+1}{n}}\right]} \tag{10a}$$

or, for air, for a round orifice of diameter d inches, the initial temperature of the air being 60° F.

$$W_{sec} = 0.000491\ d^2p_1\sqrt{\left(\frac{p_2}{p_1}\right)^{1.425} - \left(\frac{p_2}{p_1}\right)^{.172}} \tag{10b}$$

The only variable in (9) and (10) is the pressure ratio $\left(\frac{p_2}{p_1}\right)$; and if, by means of graphical method or by differential calculus, the value of $\frac{p_2}{p_1}$ for *maximum* flow is determined, the following result is obtained:

$$\left(\frac{p_2}{p_1}\right) = \left(\frac{2}{n+1}\right)^{\frac{n}{n-1}} \text{ for maximum flow.} \tag{11}$$

This is called the *critical* pressure ratio. It means that if values are calculated for W, keeping p_1 constant and gradually reducing p_2, the back pressure, the discharge increases until the critical pressure ratio is reached. If the pressure is reduced still further, the flow should begin to decrease, according to the formula, until with $p_2=0$ the flow would be zero. This is manifestly wrong, and many experimental investigations have proven that after the flow rate has reached a maximum value it remains constant, no matter how much the back pressure is reduced. Or, in other words, when this critical pressure ratio is exceeded the pressure in the mouth of the orifice is not any more identical with the pressure outside. For air with $n=1.40$ the critical pressure ratio from equation (11) is 0.528, i. e., at 53 per cent of the initial pressure the flow rate reaches its maximum value. This, as has been emphasized in another chapter, must not be overlooked by carburetor designers, since, should the pressure at the throat of the Venturi tube reach this critical value, the air flow would cease to increase, while the gasoline flow out of a nozzle located in the throat of the Venturi tube would continue to increase with the pressure drop.

The expression for maximum flow, substituting the critical value of $\left(\frac{p_2}{p_1}\right)$ from (11) in equation (10) or (10*a*), becomes

$$W_{max}=A\left(\frac{2}{n+1}\right)^{\frac{1}{n-1}}\sqrt{2g\frac{p_1}{v_1}\frac{n}{n+1}} \tag{12}$$

5. *Same conditions as for (4)—Approximating expressions for flow rates.*—Equations (9) and (10) are very awkward for numerical calculations. Equation (8) gives very simple expressions, but is accurate only for very small pressure ranges, as was shown there. To satisfy the need for simpler forms for the whole range down to the critical pressure, various approximations have been devised. One is due to Schüler, who substituted a hyperbola with the exponent unity and having its origin on the volume axis in place of the actual adiabatic curve. This results in the following expression for the velocity at the mouth of the orifice.

$$u=\sqrt{2g\frac{(p_1-p_2)}{w_1}\cdot\frac{2\,p_1-\alpha\,(p_1-p_2)}{(p_1+p_2)}} \tag{13}$$

in which $\alpha=\frac{n-1}{n+1}\cdot\frac{1}{1-\left(\frac{2}{n+1}\right)^{\frac{n}{n-1}}}$

$=0.353$ for air.

$$W=A.\frac{u}{v_2}\text{ and }v_2=v_1.\ \frac{p_1}{p_2}\left[1-\alpha\left(1-\frac{p_2}{p_1}\right)\right] \tag{14}$$

The accuracy of this expression is as follows:

For $\frac{p_1}{p_2}$	$=1.1$	1.3	1.5	1.7
Error	$=0\%$	-0.6%	-0.82%	-1.1%

6. *Flow of gases through orifices—Theoretical flow rates—Small pressure drops.*—Equation (8) which was deduced for fluids in general may be used for gas flow as long as the pressure range is very small. For the limits of accuracy, see discussion under equation (8). When the pressure ratio is less than $\frac{p_2}{p_1}=0.9$, the above given accurate equations (9) and (10) or (13) and (14) have to be used. When the pressure ratio approaches the critical value, approximate formulæ deduced from $u=\sqrt{2gh}$ in which $h=\frac{p_1-p_2}{w_1}$ are absolutely useless.

Below will be found a few enpressions based on equation (8).

Durley (Trans. A. S. M. E., vol. 27) reduces it into this form (for air flow):

For an orifice of diameter d inches,

$$W_{sec}=0.01369\ d^2\sqrt{\frac{iP}{T}} \tag{15}$$

in which i = difference of pressure in inches of water.
P = mean pressure of air in pounds.
T = abs. temperature of air in °F. (supposed to remain unchanged).

Durley says that "up to a pressure of about 20 inches of water above atmospheric pressure the results of equations (15) and the accurate formula (10) agree very closely. At higher differences of pressure divergence becomes noticeable."

When the discharge takes place into the atmosphere, P, in Durley's formula, is about 2,117 pounds per square foot, and

$$W_{sec}=0.6299\ d^2\sqrt{\frac{i}{T}} \tag{15a}$$

which is of the same form as Fliegner's formulæ:

$$W_{sec}=1.06\ a\sqrt{\frac{p_2(p_1-p_2)}{T}}\ \text{when}\ p_2>0.53\ p_1 \tag{16}$$

or for less than two atmospheres to atmosphere.

$$W_{sec}=0.53\ \frac{p_1}{T_1}\ \text{when}\ p_2<0.53\ p_1 \tag{17}$$

or for more than two atmospheres to atmosphere.

In (16) and (17) the pressures are in pounds per square *inch*. T=°F abs.

Clark, for small pressure differences, uses the form:

$$u=66.35\sqrt{h}\ \text{where}\ h=\text{pressure difference in inches of water.} \tag{18}$$

(B) ACTUAL FLOW RATES FOR GASES—RESULTS OF EXPERIMENTAL INVESTIGATIONS—COEFFICIENTS FOR FORMULAS GIVEN IN PART A, FOR GAS FLOW.

1. *Coefficients generally necessary—Reasons.*—In the formulas mentioned so far the velocity and the weight of the fluid are seen to depend only on the pressure drop and on the flow area. Experience, however, shows that the flow rate also is affected by the cross section of the *shape* of the orifice or nozzle or channel section. And by shape is meant not so much the shape of the transverse section, whether circular or oval or square or rectangular, but the contours of the longitudinal section rather. For instance, in the case of flow from a large vessel into the atmosphere through an orifice in a thin plate, the jet begins to form on the inside, the particles of fluid being accelerated toward the opening. The consequence is that the area of the cross section of the jet a short distance from the orifice is less than that of the orifice, i. e., the jet is "contracted," and while the theoretical velocity may actually have been developed, the weight discharged per unit time is

$$W = A' \cdot u \cdot w \text{ where } A' = \mu\, A \text{ and } \mu < 1$$

If, in addition, due to the viscosity of the fluid, the velocity is also reduced, the velocity becomes

$$u' = \varphi\, u \text{ where } \varphi < 1$$

The weight discharged therefore is

$$W = \mu \cdot \varphi \cdot A \cdot u \cdot w.$$

Although μ and ϕ owe their origin to radically different causes, they are usually combined into one coefficient C, so that,

$$C = \mu . \varphi \text{ and } W_{actual} = C.\, W_{theor}$$

C will be called the discharge coefficient. The contraction of the stream is caused by an abrupt change in cross section, causing eddies, and thus whenever loss of energy is to be avoided, the change from one cross section to another is made so as not to break up the natural stream lines of the fluid. An orifice therefore made with a rounded entrance gives less energy loss, hence closer approximation to the theoretical formula than an orifice in a thin plate. It does not matter much what the exact shape of the entrance portion is as long as the corners are rounded off. Even a small radius sweep will result in a very considerable improvement over the sharp edged entrance.

So far the remarks apply equally to liquid and gaseous fluids. In the case of the latter, however, another phenomenon must be concidered. The conversion of kinetic energy into heat energy, due to friction and turbulent flow, means a rise in temperature. While for liquids which are practically incompressible, this temperature rise does not mean anything else but the equivalent velocity loss, in the case of gases the resulting increase of volume must be con-

sidered. The actual volume will be greater than that corresponding to adiabatic change which was assumed in the theoretical formulæ.

2. *Actual flow of gases through orifices with well-rounded entrance.*—One of the first determinations for this case was made by Zeuner. (Zeuner, Technische Thermodynamik, 1st ed., 1887, p. 220, 2d ed., 1900, p. 256.) Zeuner found for pressures greater than twice the outside pressure, that the actual flow of air was identical with the calculated values within the experimental limits of accuracy. By these experiments, made in 1871, it was proven for the first time that the discharge remained constant when the critical pressure ratio was exceeded, thus confirming the work of De Saint-Venant. In his later and more accurate experiments with orifices of 5, 11, and 15 mm. diameter, Zeuner found the actual discharge rates to be slightly less than the calculated values, or,

$$u \simeq 0.97\ u_2, \text{ in which } u = \text{actual velocity}$$
$$u_2 = \text{calculated velocity}$$

For smaller pressure drops Weisbach had obtained the same value for the discharge coefficient, or $W \simeq 0.97\ W_2$ where W and W_2 are the actual and calculated weights discharged in unit time. Weisbach had used short nozzles (conical converging with parallel exit and well-rounded entrance). (See Grashof, Hydraulik, p. 576.)

The addition of a diverging conical part to a converging nozzle does not affect the *theoretical quantity* discharged, and this form of nozzle, which is equivalent to a so-called Venturi tube, must be expected to show the same characteristics with respect to actual flow rate as the short nozzle excepting that the added surface will increase the friction. It may be mentioned, in passing, that the correct taper for the diverging part of a Venturi tube, which has reached such prominence in carburetor design, might be calculated from the pressure-volume relations in adiabatic flow so that the minimum pressure drop would take place, i. e., the minimum disturbance; but in the first place the calculations would be correct for one-flow rate only, and a mean value would have to be adopted, and, furthermore, since one of the principal objects in introducing a Venturi tube is to produce a good mixing effect, it would seem that the more turbulent the flow is the better it would be for general efficiency, and that good stream lines are not wanted at all. Nozzles have been investigated by many experimenters on account of their importance for steam turbines and for air and other gases—with a view toward their use in gas turbines and for the purpose of measuring large quantities of air such as the discharge of air compressors. Unfortunately, however, most of these experiments were made for pressure ranges near or beyond the critical pressure ratio—Stodola's nozzle experiments are perhaps the best known. (See his book, Die Dampf turbinen, Springer, Berlin.) Although most of his work referred to steam, a study of his investigations is most helpful to the understanding of some of the peculiar phenomena in nozzle flow.

The calculation of the discharge of nozzles which have a restriction in area, i. e., convergent-divergent nozzles, is based on the smallest cross section.

A very complete investigation of the properties of nozzles for air flow has lately been made by Thomas B. Morley, who read a paper

before the Institution of Mechanical Engineers, published in Engineering January 28, 1916. The nozzles had throat diameters between 0.193 and 0.196 inch and were made with different tapers and different lengths, all converging-diverging and all with more or less rounded entrance. Similarly to most of the nozzle and orifice investigations, the air was allowed to escape into the atmosphere from a large closed reservoir while the time rate of change of pressure and temperature in the reservoir was being observed. Initial pressures from 50 to 75 pounds per square inch abs. were used, and the discharge coefficients varied between 0.95 and 0.98. The lower values belonged to the long nozzles and for those with overrapid divergence. The coefficients were *constant* for the whole pressure range.

From all the experiments which have been quoted in this section, it follows that for orifices or nozzles with well-rounded entrance the discharge coefficients are very nearly unity.

Sanford A. Moss (see also his article on Discharge Coefficients for Air Flow, American Machinist, vol. 28, No. 3, p. 14) states (Journal A. S. M. E., September, 1916) that the discharge coefficient of a well-made Venturi tube for air is within 1 per cent of the theoretical flow.

3. *Actual flow of gases through orifices in thin plates and sharp-edged orifices diverging in the direction of flow.*—Such orifices have a very much lower discharge coefficient than the ones just mentioned, due, of course, to the great contraction.

For orifices in thin plates (sheets) of 0.394 inch up to 0.843 diameter, Weisbach (see Grashof, Hydraulik) found discharge coefficients varying between 0.55 and 0.72. The pressure ratios ranged from 1.05 to 1.65. The discharge coefficients increase very appreciably with increase of pressure difference, and are slightly less for large openings than for smaller ones.

Zeuner, for a round, sharp-edged orifice, reported discharge coefficients very nearly the same as for Weisbach's at a pressure ratio of 1.5, but after that the coefficient continued to increase even after the critical pressure had been exceeded and at a pressure ratio of 4.1 it was 0.83, beginning with 0.65 at 1.5 pressure ratio. This peculiar result apparently has not been observed by anyone else, according to Schüler, and must be accepted with caution.

Morley included one sharp-edged orifice in his nozzle experiments. (See above.) The orifice, 0.196-inch diameter, was made in a thin flat disk. The sides were beveled off, but the edge was not made sharp, a very thin cylindrical piece being left.

With the beveled side on the side of the tank, the discharge coefficient increased from 0.758 at 25 pounds per square abs. to 0.858 at 50 pounds per square abs., the back pressure being atmospheric. This corresponds to pressure ratios of about 1.7 and 3.4, respectively, i. e., near and beyond the critical ratio. The higher value agrees with Zeuner's. Moreley also reversed the disk so that the beveled side of the orifice was on the outside, and naturally obtained lower values, the coefficients for the same pressure range increasing from 0.73 to 0.84.

A. O. Müller (Forschungs-Arbeiten No. 49) investigated the flow for sharp-edged orifices similar to those last mentioned, but for very small pressure drops, about 5 to 50 mm. of water (0.2 to 2 inches).

His determinations, made with very great care, give for these conditions a discharge coefficient of 0.597, considerably more than Zeuner. Details could not be obtained.

Frequently quoted are the coefficients which were obtained by R. J. Durley. (Trans. A. S. M. E., vol. 27.) The orifices were bored in plate 0.057 inch thick. The results are given for orifices up to 6 inches diameter and for heads up to 6 inches of water. The principal conclusions were that for small orifices the coefficient increases as the head increases, but at a lesser rate the larger the orifices till for the 2-inch orifice it is almost constant. For orifices larger than 2 inches it decreases as the head increases, and at a greater rate the larger the orifice. The coefficient as the diameter of the orifice increases and at a greater rate the higher the head. The discharge coefficients varied between 0.59 for a 4½-inch orifice and 0.618 for a five-sixteenths-inch orifice, at a head of 6 inches of water. At 2 inches pressure difference the variation is even less, between 0.595 and 0.607, a mean of 0.601, which is within 0.67 per cent of Müller's figure, 0.597.

4. *Actual flow of gases over poppet valves.*—In 1905 Charles E. Lucke published a paper on the pressure drop through poppet valves (Trans. A. S. M. E., vol. 27), which is of interest on account of the use of poppet valves for auxiliary air inlets. Both flat and conical valves were investigated and the discharge coefficients are given. Naturally they vary between rather wide limits.

5. *Actual flow of gases through short tubes with sharp-edged entrance.*—In this case contraction will occur inside the tube near the entrance. If the tube is long enough the jet will fill the whole of the tube some distance from the contracted part and leave the tube with full cross section. The pressure at the point of contraction actually falls to a value less than the final, so that the velocity at that point is greater than the one corresponding to the over-all pressure drop. The weight discharged is less than that due to flow through an orifice with well-rounded entrance, but considerably greater than in the case of plain sharp-edged orifices. The fact is that the jet actually takes the shape of a converging-diverging nozzle (De Laval nozzle) and if the pressure ratio is greater than the critical pressure, the velocity of efflux may actually be greater than that due to the drop to the critical pressure.

According to Weisbach, for a short cylindrical tube 10 mm. in diameter with sharp edges the discharge coefficient for air varies from 0.75 at 1.05 pressure-ratio to 0.82 at 1.28 ratio. Zeuner, for the same kind of tube and 1.72 pressure-ratio, gives 0.85.

6. *Actual flow of gases through orifice in thin plate, but initial velocity not negligible.*—This case is of special interest since the construction is extensively used for measuring air flow. Ordinarily it is not used in carburetors. It is produced by inserting in a pipe a disk with an opening smaller than the pipe area. The contraction is not as great as in the case of flow from a large vessel, since the particles of air are already in motion and have to be deflected only very little, if the reduction in area is small.

A. O. Müller (see above) found values for the coefficient of discharge to vary from 0.641 to 1.084, depending on the ratio of cross section. The smaller the cross section the greater the loss.

E. O. Hickstein, in a paper before the American Society of Mechanical 9ngineers in December, 1915, communicated the results of tests made by him along the same line as Müller's, and the results of the two investigations check fairly well.

7. *Actual flow of gases—Loss of head in pipes.*—As was mentioned at the beginning of this chapter, two kinds of flow may be distinguished, viscous and turbulent flow. In the former, which is only possible at very low velocities, the layer of fluid near to the pipe walls sticks to the latter by adhesion and is therefore stationary. The next layer must be pushed over the first, the third over the second, and so forth, to the center of the pipe where the velocity is a maximum. This relative motion of the layers is resisted by what is called the viscosity of the fluid. Thus in viscous flow the resistance is due only to the viscosity of the fluid. When the velocity reaches a certain limit, called the critical velocity, small disturbances, eddies, begin to form, and soon the whole stream will be in a state of turbulence, such as is shown by the smoke issuing or "rolling" from a stack. Since pure viscous flow is possible only at the very lowest velocities, and since it is out of the question to devise a theoretical formula for turbulent flow of gases, all expressions for loss of head in pipes are empirical. But even so they can not be of a simple nature if they are to be generally applicable. Any such formula must involve at least the rate of flow, specific volume of air, pressure of air, diameter of pipe, length of pipe, and the head required to maintain the flow. Since the pressure is decreasing the specific volume is increasing, which again means acceleration. The condition of the pipe surface requires a separate coefficient.

The roughness of the surface, more or less pronounced in all unfinished parts, delays the motion of the particles of air. They bound off and are projected laterally into the air current, causing more disturbance and requiring to be accelerated anew.

Formulæ for pipe resistance of which any number exist and which may be found in handbooks and textbooks, are usually of the form $d\,p=\frac{f\,l\,u^2}{2\,g\,m}$ where $d\,p$ is the difference of pressure at the two ends of a long pipe of length 1, and of hydraulic mean depth m (m = diameter ÷ 4), due to a flow with mean velocity u. This equation, as Prof. Gibson (Engineering, Nov. 22, 1912) points out, only applies if the coefficient f is varied, not only with the physical condition of the interior surface of the pipe, but with its diameter, with the mean velocity of flow, with the mean pressure, and with the temperature of the air. Prof. Gibson therefore devised a formula in which the effect of these variables was expressed, and arrived at a formula of the following form,

$$d\,p=K\frac{p^{n-1}\,.\,u^n}{a^n\;d^{3-n}}\cdot\frac{u^{2-n}}{(CT)^{n-1}}$$

in which K and a are numerical constants; p and u are the mean absolute pressure and velocity in the pipe, u is the viscosity and T the absolute temperature of the air; C is obtained from the equation $p\;v=CT$; d is the pipe diameter; and n is a numerical index depending on the size and kind of pipe. The author of this formula tested it on a number of pipes for which the flow rate had been deter-

mined and obtained excellent agreement. For all cases of flow where the air is at atmospheric temperature, the drop in pressure is given with a high degree of accuracy by

$$d\,p = 0.0000346\,\frac{p^{n-1} \cdot u^{n} \cdot l}{6.6^{n} \cdot d^{3-n}}$$

Here d and l are in feet, and p in pounds per square inch absolute. Tables are given for the value of n for different pipes and also corrections for temperatures other than 65° F.

Now, considering the nature of the carburetor problem, it is hardly likely that formulæ like the above will ever be used very much by the designer, but there is need for establishing experimentally the laws of flow resistance for such sections as are employed in the modern carburetor and manifolds.

Information on the effect of bends is incomplete. Kent (Mechanical Engineer's Pocket Book, 8th ed., p. 593) gives the effect of elbows and tees in terms of the equivalent length of straight pipe producing the same pressure drop, but the applicability to carburetors and manifolds is doubtful to say the least.

That empirical formulæ for the flow of air through large channels, such as ventilating ducts and smokestacks, on which a great deal of reliable information has been collected, will be of no use in carburetor work is self-evident.

(C) ACTUAL FLOW RATES FOR LIQUIDS—RESULTS OF EXPERIMENTAL INVESTIGATIONS—COEFFICIENTS FOR FORMULAE GIVEN IN PART A FOR FLOW OF LIQUIDS.

1. *General considerations.*—The general flow laws do not differ in principle for liquids and gases, so that practically the whole of the theoretical part of the discussion in part B applies equally well to liquids and need not be repeated.

Hydraulics is one of the oldest branches of science, and naturally there is a vast storehouse of information on everything, it would seem, pertaining to the flow of liquids. Unfortunately, however, practically all of this stored-up information is useless when we come to carburetor problems, for the simple reason that the passages which matter—those that affect the flow rate—are so small that at the velocities used they have to be classed among capillary tubes and passages. The other passages between float chamber and jet are simply made large enough and can easily be made large enough so that the velocity in them is negligible.

The problem consists in controlling the fuel flow by means of the air flow so that the proportions of air to fuel by weight is maintained constant or varied according to some predetermined rule.

The fundamental laws for the flow of liquids are exactly the same as those for gases, and there is no foundation for the general statement often made that in a carburetor with fixed nozzle and fixed air inlet the mixture becomes richer, as the flow increases, because they "do not follow the same law." The broad flow laws are the same for both media, but they do not work under the same conditions on account of the small dimensions of the fuel control passages, or

otherwise, the special forms of the flow laws for the particular air and fuel passages may be different, and usually are.

Partly the difficulty is of course due to the circumstance that the level of the fuel in the float chamber necessarily is lower than the mouth of the spray nozzle, since the fuel must not overflow when the engine is not running or when the engine is tilted. This results in a certain lag in the fuel flow, i. e., the air must have a certain velocity before the fuel will begin to flow at all. This condition is represented by the equation

$$u=\sqrt{2g(h-h_0)}$$

where u=velocity of fuel, h=suction head due to the air flow, and h=difference in level between float chamber and mouth of spray nozzle. That this only partly accounts for the discrepancy can easily be proven and has been proven by raising the level in the float chamber until it is flush with the mouth of the nozzle. Even then the fuel increases more rapidly in proportion to the air.

2. *Flow of liquids through small orifices.*—The first investigator who attacked this problem in a thoroughgoing manner was Prof. K. Rummel, Aachen, Germany, who conducted a series of tests covering a period of three years, and published the results in Der Motorwagen in 1906. (See translation in Horseless Age, Apr. 14, 1915.) The laws of liquid flow were known for two special conditions, viz, flow through a relatively long capillary tube,[1] and through orifices in the walls of large vessels. The carburetor nozzle represents an intermediate case. Prof. Rummel developed a mathematical theory of the flow and substantiated his deductions by quantitative tests. Water was used for the sake of safety and accuracy, and was perfectly satisfactory since only qualitative results were looked after.

Rummel refers to the work of Krebs, the inventor of the spring-loaded auxiliary air valve. (Revue Industrielle, 1903, No. 1.) Krebs used for the fuel flow the formula,

$$u=\sqrt{2g(h-h')},$$

and Rummel points out that this h' has to correct—

(*a*) The difference in level, as mentioned before; and

(*b*) Capillary frictional resistances in the nozzle which, therefore, in contrast to the general views on the subject,. are assumed to be independent of the velocity.

Krebs then finds it necessary to introduce another correction factor to allow for the pulsating flow of the engine at higher speeds.

Still Rummel objects, and correctly so, to the implied assumption that capillary flow is independent of speed.

Poiseuille first established the law of capillary flow (Annales de Chimie et de Physique, 1843, series 3, vol. 7), with the equation $p\gamma=u\frac{32l}{d^2}\eta$ where $p\gamma$=frictional resistance, u=velocity, l=length of tube, d=diameter, and η=coefficient of viscosity.

Reynolds (Phil. Trans., London, 1883, A 174, p. 935) was the first to determine the critical velocity where turbulent flow begins and

[1] See values given by Sorel.

which was explained before. Above the critical velocity, Reynolds found the friction to vary as the 1.7 power of the velocity, but the values of u in carburetors lie uniformly below Reynold's critical velocity, therefore Poiseuville's law is valid. Unfortunately, even this law is not absolutely correct for short tubes like carburetor nozzles, and a correction is necessary.

Taking all these factors into consideration, Rummel deduces a theoretical equation which shows that a variation of the mixture proportions must actually occur unless additional air is admitted. The form of this equation is,

$$p\gamma = c_1u + c_2u^2.$$

The experiments subsequently made on nozzles of various kinds substantiated the correctness of the form of the equation. Prof. Rummel draws some very interesting deductions from the values obtained by him, but no useful purpose would be served in quoting these in this place. Assuming the form of his expression for the flow rate to be correct, nothing would be left but to find by experiment the proper coefficients for nozzles of different kinds, and the scientific basis for carburetor design as far as proportioning is concerned would be established. Now Rummel's investigations were published in 1906 and since then, especially in the last four or five years, very important work in this field of research has been done, and even if the general form of his equation is found to be not generally applicable, to Rummel belongs the great distinction of having once for all shown that no headway can be made in discovering the "mystery" of carburetor nozzle flow as long as investigators do not get away from the $\sqrt{2gh}$ law which simply does not apply. In spite of Rummel's work, however, and all that has followed, the impossible attempt is still persisted in, as the carburetor literature plainly shows.

The results which have been accomplished in the last few years are very well summarized by Dr. Charles H. Lees in the introduction of an article on "Laws of skin friction" (Engineering, June 2, 1916), which deals, not with carburetors, but with the resistance experienced by ships. This only illustrates the significance of the fact that the study of viscosity has helped to throw light on many problems which hitherto have resisted all attempts at rational solution.

Dr. Lees's summary is herewith given verbatim:

On the frictional resistance to the flow of fluids through pipes.

When a fluid of density ρ flows through a length l of a smooth pipe of diameter d with a mean speed over the section of the tube of v, not sufficiently large to cause the motion of the fluid to deviate from stream-line motion, the frictional resistance F to its motion is given according to Stokes by:

$$F = 8\pi\eta\, l\, v$$

where η is the viscosity of the fluid. When the speed of the fluid is increased above a certain value, called by Reynolds the "critical velocity" for that fluid and pipe, the frictional resistance increases

faster than the first power of the velocity, and at high speeds becomes nearly proportional to the square of the mean velocity. We propose to call the motion under the first law "stream-line motion," and when deviation from this law commences to call the motion "eddying or turbulent motion."

The experimental results obtained by Stanton and Pannell at the National Physical Laboratory in the turbulent flow of water and other fluids through smooth brass pipes of diameters 0.3 to 12 cm. at speeds from 5 to 5,000 cm. per second, and those obtained by Saph and Schoder at Cornell University on water in pipes from 0.3 to 5 cm. diameter, have been shown recently to lead to the following simple formula for the total frictional resistance F of a smooth pipe of length l, diameter d, through which a fluid of kinematical viscosity γ is flowing with mean speed v:

$$F=\pi\rho l d v^2\left\{a+b\left(\frac{\gamma}{d.v}\right)^n\right\}=A\rho v^2\left\{a+b\left(\frac{\gamma}{d.v}\right)^n\right\}$$

where A is the area of the surface of the length of pipe, $a=0.0009$, $b=0.0765$, $n=0.35$, whatever be the fluid or the system of units used.

From the form of this expression it will be seen that for all mean velocities above the critical, for which

$$\frac{d\,v}{v}=3000 \text{ about}$$

the resistance over small ranges of velocity will vary approximately as a power of the velocity between 1.65 and 2.0 and that, as the diameter of the pipe increases, or the speed increases, or the kinematical viscoscity decreases, the resistance will vary more nearly as the square of the velocity.

The single power of the velocity which gives the best approximation in the neighborhood, of a particular value of $\frac{d\,v}{v}$ is:

$$n_1=2.\frac{1+\left(1-\frac{n}{2}\right)\frac{b}{a}\left(\frac{\gamma}{d.v}\right)}{1+\frac{b}{a}\left(\frac{\gamma}{d.v}\right)^n}$$

The references quoted by Dr. Lees are the following: Stanton and Pannell (Phil. Trans. Royal Society, A, vol. 114, p. 199, 1914); Saph and Schoder (American Society of Civil Engineers' Proceedings, vol. 51, p. 253, 1903); Lees (Roy. Soc. Proc., A, vol. 91, p. 49, 1914). Recently Lander has shown that with $a=0.002$, $b=0.141$, $n=0.44$, the formula covers his measurements on the flow of water and steam through small rough, wrought-iron pipes. (Roy. Soc. Proc., A, vol. 92, 1916.)

It would seem advisable to follow Dr. Lees's practice, and name all flow below Reynold's "critical velocity" simply "stream line motion" and above this velocity "turbulent flow." There is also the danger that the designation "capillary tube" and "capillary

flow," which are so glibly used in the carburetor literature, are misunderstood. Since not small dimensions, but dimensions *and* velocity together with the viscosity of the fluid determine whether the formulæ for stream line flow or those for turbulent flow should be applied, the title "capillary tube" seems to have no significance whatever, as far as flow is concerned.

The form of equation given by Lees differs from Rummel's formula inasmuch as the second term does not contain the first power of the velocity, but the 1.65 power. It must, however, be noted that Rummel used tubes of 0.0375 cm. up to 0.0720 cm. diameter and various lengths while Stanton and Pannell employed smooth brass pipes of diameters 0.3 to 12 cm. and Saph and Schoder pipes of 0.3 to 5 cm. diameter.

That the laws of stream line flow, as formulated by Stanton and Pannell, hold for larger pipes, was established by the most interesting and instructive investigation of "Viscosity of oil in relation to its rate of flow through pipes," by Dr. R. T. Glazebrook and Messrs. W. F. Higgins and J. R. Pannell, who presented the results before the Institution of Petroleum Technologists in November, 1915. (See Engineering, Nov. 19, 1915.) The object of the research was to investigate the laws of flow of the oil in drawn-steel pipes of 3 to 5 inches diameter with a view to determining how far the pressure difference required to produce a given flow could be calculated from a knowledge of the pipe dimensions and the viscosity of the oil. As had been expected it was found that the ordinary loss of viscous flow (stream line flow) occurred as long as the velocity of flow was less than the critical velocity. The latter is given by Dr. Glazebrook as

$\rho V d/\eta = 2{,}500$, where
V = velocity of flow in feet per second,
d = diameter of the pipe in feet
ρ = density of the oil
η = viscosity coefficient of the oil,

expressed in foot-pounds-second units (not in dynes per square centimeter, as is usually done). Interesting in this paper are also the determination of the physical constants of the oils and peculiar characteristics of some of the oils.

Now that the way has been shown, the procedure should be to analyze the various determinations of flow rates which have been published, in the light of what is now known about viscous or streamline flow, to make new determinations for all kinds of nozzles and channels, to fix the value of the viscosity coefficient for all fluids in use, and to standardize the method of determining and expressing the viscosity coefficient.

Such work, for instance, as Mr. Robert W. A. Brewer has done, and an account of which may be found in Carburetion, by R. W. A. Brewer, D. Appleton & Co., and in a number of periodical articles, is extremely valuable no doubt, but as long as the many experiments which Mr. Brewer has made are only used to furnish coefficients for a formula of the form $Q = C. A. \sqrt{2gh}$, not much is gained. Brewer himself says that this coefficient of discharge applies only to a *portion* of the curve plotted with fuel discharge as ordinates and air velocities as abscissæ.

Brewer shows by actual test results that in the case of the round-hole orifice the fuel flow tends to increase too rapidly, while for an annular orifice such as is produced by a metering pin, the fuel flow lags behind. He tried, therefore, to devise an orifice which would balance the two against each other by combining the two actions in one orifice and one metering pin, the latter being of a special shape. Brewer's methods "for designing" a carburetor are, after all, nothing but cut-and-try methods, and that is exactly what should not have to be done.

It was hoped that it would be possible to analyze some of the last-named investigations, as well as others published, but unfortunately time did not permit.

REPORT No. 11.

PART VI.

NEW EXPERIMENTAL DETERMINATIONS OF THE PROPORTIONING ACCURACY OF A SELECTED NUMBER OF TYPICAL AMERICAN COMMERCIAL CARBURETORS UNDER VARIATIONS OF FLOW CONDITIONS.

By Charles E. Lucke.

(A) NEW TEST RESULTS ON CARBURETOR PROPORTIONALITY.

The primary purpose of these tests was to determine the ratio of air to gasoline maintained by fairly representative modern carburetors under all conditions likely to arise in practical use and thus to determine their flow characteristics and accuracy of compensation at all flow rates. Since it was neither feasible nor necessary for this purpose to test all existing carburetors, a set of 10 representative type forms was selected, and it must be distinctly understood that the carburetors which were tested were not chosen because they were regarded as the best carburetors in the market, but merely because each one is well known, more or less widely used, and represents a distinct type of construction. The results obtained must be judged as typical of the class and not of the individual make only. Every known method for testing carburetors has been considered or actually tried out in the laboratory of the mechanical engineering department of Columbia University, but for one reason or another none has been found satisfactory but the method which suggests itself first, namely, to attach the carburetor to an engine. Running the engine, however, and absorbing the power by some form of dynamometer makes it extremely difficult, if not impossible, to maintain constant conditions for each run and to have these conditions the same for each type of carburetor. Since proportionality only was to be investigated and the problem, therefore, consisted in measuring the gasoline and the air under various flow conditions, the engine with open ignition circuit was driven by an electric dynamometer motor so that the speed could be maintained at any desired value with very great accuracy. In other words, the engine was used as a pump or exhauster only, but with the advantage over a blower or ejector type of exhauster that the conditions in the carburetor were exactly the same as they would be with the engine running on its own power, and any accidental backfiring could take place without danger.

The engine used for the tests was an eight-cylinder Curtiss model OX aeroplane engine, and the dynamometer, driving the engine, a 150 horsepower Sprague electric dynamometer, with switchboard and resistances as regularly supplied. The engine mounting and its con-

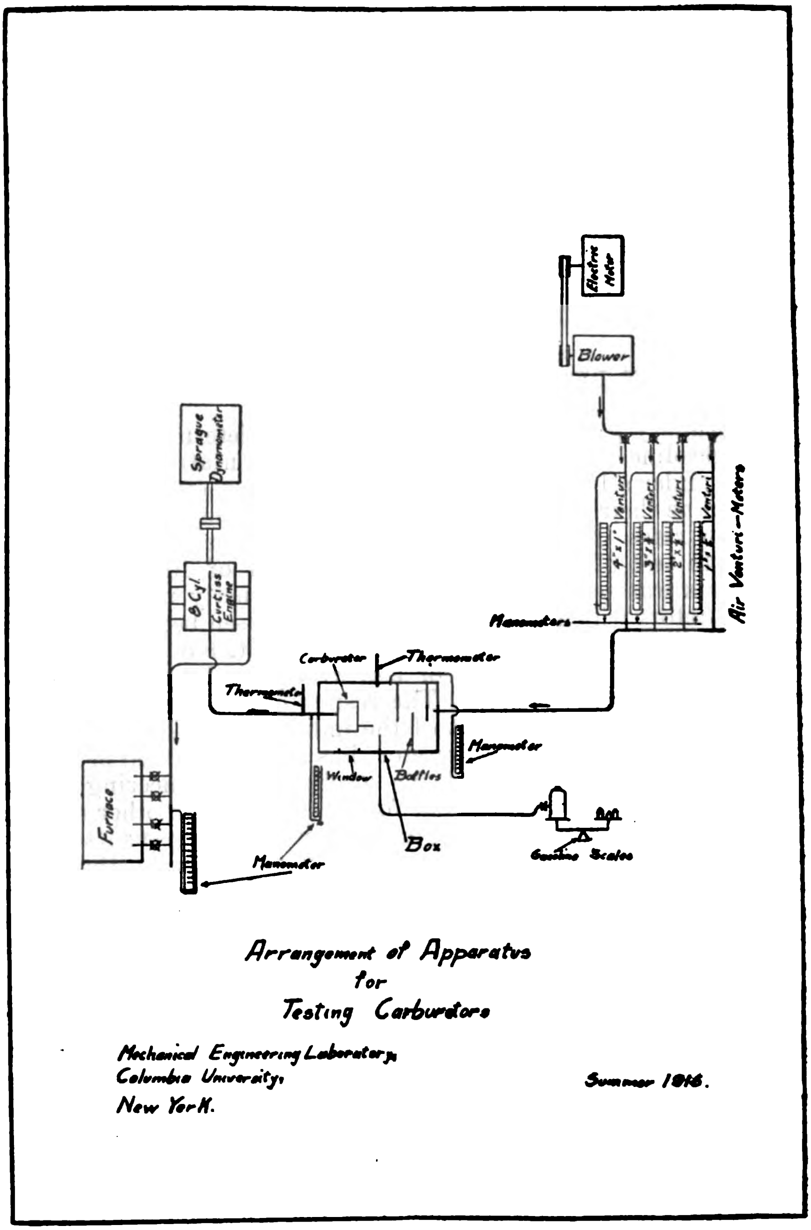

Electric Motor
Blower
Sprague Dynamometer
8 Cyl.
Curtiss Engine
Venturi
Venturi
Venturi
Venturi
Air Venturi-Meters
Manometers
Carburetor
Thermometer
Thermometer
Manometer
Window
Baffles
Box
Gasoline Scales
Furnace
Manometer
Arrangement of Apparatus
for
Testing Carburetors
Mechanical Engineering Laboratory,
Columbia University,
New York.
Summer 1916.

FIG. 1.

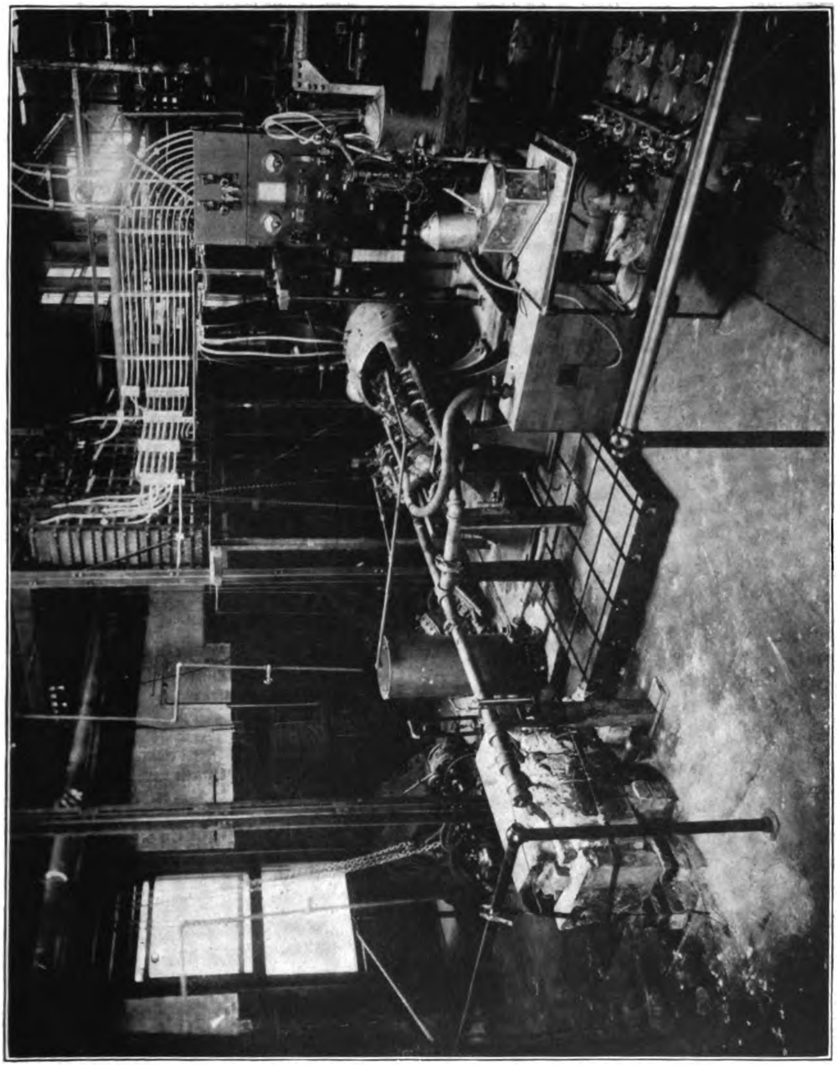


Fig. 2.

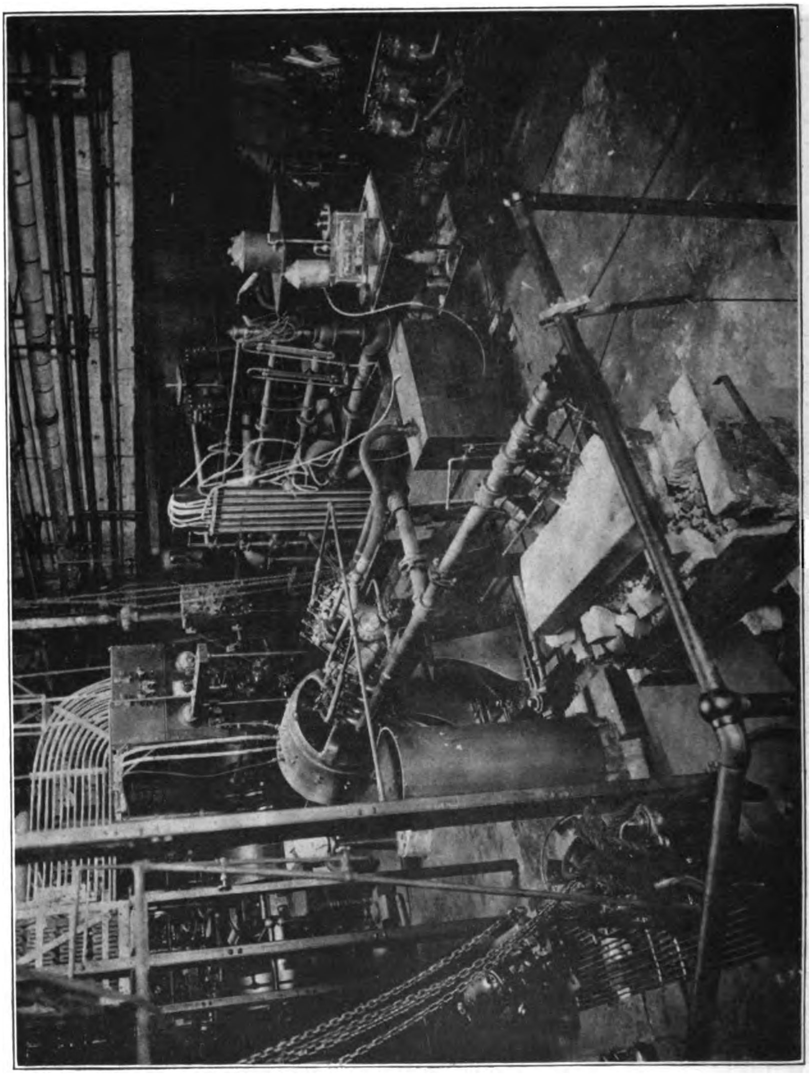


FIG. 3.

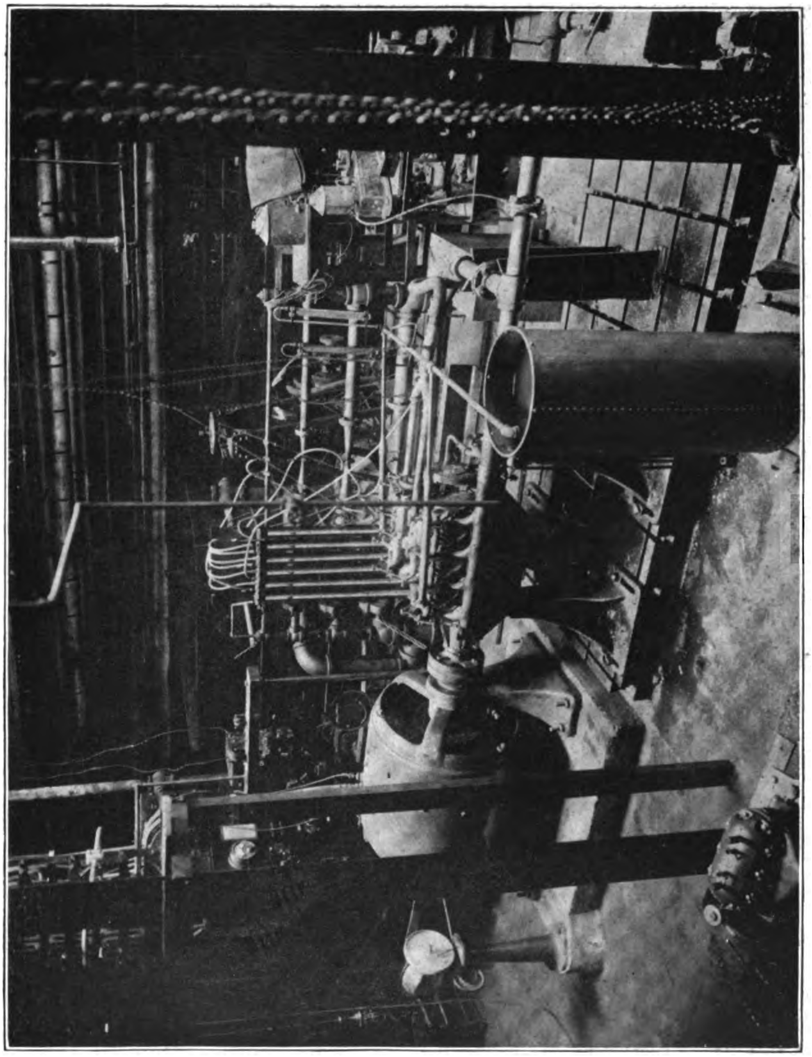


Fig. 4.

nections, as arranged for the tests, are illustrated in the diagram, figure 1, and in the three photographs, figures 2, 3, and 4.

The mixture discharged from the engine was burned in a crudely constructed surface combustion furnace, the mixture pressure in the exhaust line being regulated to the required value by means of burner valves of different sizes, so as to maintain sufficient mixture speed in the nozzles to prevent back flashing. This was considered the safest method under the circumstances and proved quite convenient and satisfactory in use. At the same time, by observing the nature of the flame, a great deal of time was saved in the adjustment of the carburetor, because with a little experience the mixture quality can be judged approximately by the flame size and color.

The carburetor to be tested was placed wholly within a specially constructed tight wooden box, 34 by 12 by 21 inches, serving as an air reservoir, in which the pressure could be maintained at any desired value, and was kept at one atmosphere while air was supplied by a blower through meters. The inside of the box was illuminated by an incandescent lamp, and through a window the carburetor and the fuel level gauge glass on the float-chamber could be plainly seen. A handhole and cover were provided for changing carburetors and for adjustments. The throttle could be operated and fixed in position without opening the box by means of lever rods, and a spindle passing through a stuffing box with an indicator and dial on the outside of the box. Every effort was made to have the box absolutely air-tight, but, in any case, since during the present tests the pressure inside the box was maintained at atmospheric pressure within one-tenth of 1 inch of water the absence of any appreciable leakage was absolutely assured.

The gasoline was supplied from a can standing on platform scales, the latter reading to one-thousandth of a pound, and by means of flexible tubing conducted to the carburetor inside the box. The time required to consume a given weight of fuel was read on a stop watch.

The air passed through a Root blower, driven by an electric motor, to one of four Venturi tubes, 4 by 1 inch, 3 by $\frac{3}{4}$ inch, 2 by $\frac{1}{2}$ inch, and 1 by $\frac{1}{4}$ inch, respectively, which were fixed between two headers, valves at the upstream ends shutting off all tubes except the one suitable for the particular condition of each run. By manipulating a slide on the intake of the blower and a by-pass valve on the discharge side the pressure in the box was easily maintained at the desired value. The upstream pressure as well as the drop between upstream and throat were read on water manometers about 4 feet high, which are plainly visible in the illustrations.

The Venturi tubes were constructed for the purpose by the Good Inventions Co., of Brooklyn, N. Y., and every possible precaution taken to have them perfect. After the readings for gasoline weight and air flow were taken, the quantities of air and fuel per minute were calculated immediately. To simplify the calculations for the quantity of air from the Venturi tube manometer readings a straight line diagram (fig. 5) was prepared, which enabled the result to be read off directly. The formula on which the diagram is based is given on the same sheet, and the use of the diagram is indicated by the dotted lines.

The tests fulfilled in every way and even surpassed the expectations with respect to the use of Venturi tubes as meters for air meas-

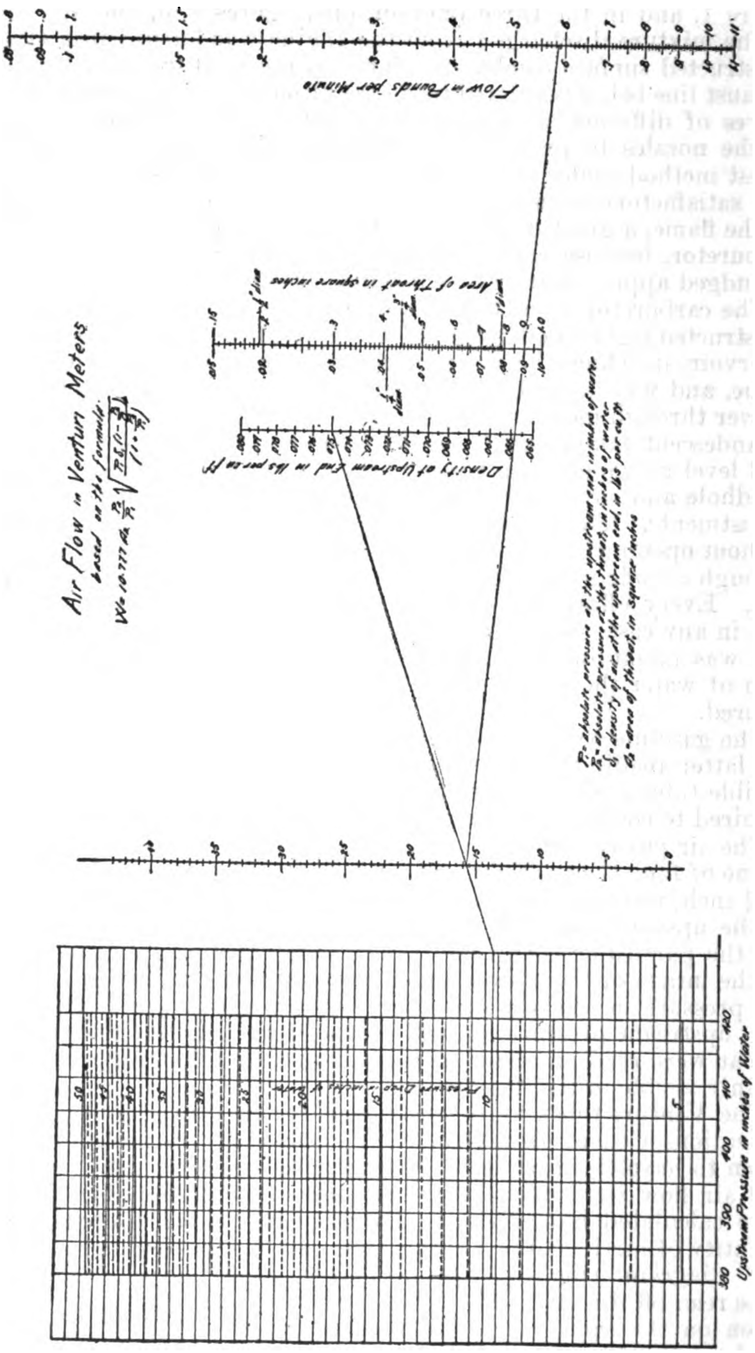

Air Flow in Venturi Meters
based on the formula
Flow in Pounds per Minute
Area of Throat in square inches
Density of Upstream End in lbs per cu ft
Pressure Drop in inches of Water
Upstream Pressure in inches of Water

Fig. 5.

urement. No more convenient method could be desired as long as sudden fluctuation need not be dealt with, and the results confirm the claim that in a properly designed and carefully constructed Venturi tube the total pressure drop is in practically all cases negligible. The readings show (see column marked "Pressure at inlet to Venturi," which gives the total pressure drop, the downstream pressure being atmospheric) that the loss in pressure varies between one-fourth and one-sixth, the drop from upstream to throat. Therefore, 75 to 85 per cent of the pressure drop at the throat is regained in the diverging part of the tube at the end. Even with an ordinary manometer pressure may easily be read within one-tenth of an inch of water, so that the over-all pressure drop need not be more than, say, 2 inches of water for sufficient accuracy, generally a negligible drop. If a differential manometer be used, even a lower value for the minimum drop will be satisfactory. Time for a strict calibration of the Venturi tubes was not available in the short period allowed for the work, but since all authorities agree that the velocity coefficient is very nearly unity (in no case less than 0.99 for a properly constructed tube) and is constant, calibration was considered unnecessary for the purpose of these tests. That the tubes are properly constructed is proven by the very small over-all pressure drop. (See remarks by Sanford A. Moss, Jour. A. M. I. E., Sept., 1916, p. 720.)

The use of Venturi tubes for the measurement of the air supplied to the carburetor of course precluded tests intended to bring out the behavior of the carburetor when the flow suddenly increases or decreases. No method for measuring air would seem to be applicable under these conditions, and the quality of the mixture must be judged by the behavior of the engine running on its own power. Baffle plates in the box served to break up the velocity of the air. The carburetor was connected to the inlet manifolds by a flexible metallic hose.

For each run the speed of the dynamometer and engine was regulated, then the pressure in the box was brought to atmospheric, and the following readings were taken:

(1) Upstream pressure of Venturi.
(2) Drop between upstream and throat of Venturi.
(3) Pressure in carburetor box (atmospheric).
(4) Pressure at outlet of carburetor or mixture pressure in manifold intake by mercury manometer.
(5) Temperature in carburetor box.
(6) Temperature of mixture at outlet of carburetor.
(7) Engine speed (not necessarily very accurate as long as speed was kept constant).
(8) Weight of gasoline, and time consumed.
(9) Scale on gauge glass of float chamber, which was specially attached to each carburetor so as to make possible a measurement of the level of the gasoline and to observe its fluctuations.
(10) Pressure in exhaust pipe of engine, taken only for the purpose of regulating back pressure.
(11) Barometer reading.

These readings for the several runs are recorded in the log sheets, Tables II, III, IV, V, VI, VII, and VIII.

TABLE II-VIII.—*Log of carburetor tests, Columbia University, June to August, 1916.*

CARBURETOR NO. 1.

[June 27, 1916; average barometer, 29.84 inches; gasoline, S. G., 0.7275.]

Run No.	Venturi meter.				Pressure at Venturi inlet, inches water.	Pounds air per minute.	Pounds gas per minute.	Ratio.	Pressure drop across carburetor, inches mercury.	Pressure in box.	Temperature, °F.		Engine revolutions per minute.	Throttle opening No.	Level in float chamber, inches.	Total pounds mixture per minute.
	Size, inch.	Left, inches.	Right, inches.	Height, inches water.							Inlet to carburetor.	Outlet from carburetor.				
1	1	11.5	15.9	27.4	4.0	8.12	0.630	12.90	2.10	0	82	55	1,000	Full.	0.75	8.75
2	1	11.6	16.0	27.6	4.0	8.19	.627	13.10	2.10	0	84	56	1,000	Full.	.88	8.82
3	1	8.2	12.8	20.5	2.5	7.15	.562	12.70	2.60	0	84	56	800	Full.	1.00	7.71
4		20.0	21.2	41.2	7.4	5.50	.445	12.35	1.60	0	84	56	600	Full.	1.15	5.95
5		14.0	14.8	28.8	3.8	4.69	.383	12.25	1.40	0	85	57	510	Full.	1.25	5.07
6		21.5	19.7	41.2	7.8	2.84	.260	10.95	0.85	0	86	58.5	320	Full.	1.35	3.10
7		19.8	18.3	88.1	7.8	2.75	.250	11.00	1.80	0	87	58	320	2	1.40	3.00
8		11.8	12.5	24.3	5.0	4.37	.360	12.15	3.50	0	86	59	510	2	1.20	4.73
9		14.3	15.5	30.3	5.8	4.78	.410	11.65	4.50	0	86	58	600	2	1.15	5.19

CARBURETOR NO. 2.

[June 28, 1916; average barometer, 29.78 inches.]

Run No.	Size, inch.	Left, inches.	Right, inches.	Height, inches water.	Pressure at Venturi inlet, inches water.	Pounds air per minute.	Pounds gas per minute.	Ratio.	Pressure drop across carburetor, inches mercury.	Pressure in box.	Inlet to carburetor.	Outlet from carburetor.	Engine revolutions per minute.	Throttle opening No.	Level in float chamber, inches.	Total pounds mixture per minute.
10		20.9	22.3	43.2	8.5	5.60	0.442	12.7	5.9	0	84	56	800	2	1.15	6.04
11		21.5	22.8	44.3	7.8	5.65	.458	12.3	6.1	0	84	55	1,000	2	.95	6.11
12		21.2	22.3	43.5	7.8	5.60	.478	11.7	6.1	0	84	56	1,200	2	.95	6.08
13	1	9.5	13.3	22.8	2.8	7.50	.600	12.5	2.6	0	85	56	1,200	Full.	.95	8.10
14		3.4	3.5	6.9	2.0	1.06	.118	9.0	13.1	0	92	56	950	3	1.50	1.18
15		3.5	3.4	6.9	2.4	1.06	.115	9.2	14.0	0	92	55	810	3	1.50	1.18
16		3.2	3.2	6.4	2.2	1.04	.112	9.3	14.6	0	92	56	605	3	1.50	1.15
17		3.1	3.1	6.2	2.3	1.01	.112	9.04	14.1	0	92	57	450	3	1.50	1.12
18		2.7	2.7	5.4	1.8	.95	.100	8.74	11.8	0	92	58.5	290	3	1.50	1.06
19		2.7	2.7	5.4	2.0	.95	.102	9.3	11.6	0	94	60	1,200	3	1.50	1.05
20		19.8	17.7	37.5	7.2	2.32	.225	10.3	7.3	0	92	60	1,200	4	1.50	2.55
21		10.9	17.3	37.2	7.3	2.32	.215	10.8	8.2	0	92	64	1,000	4	1.45	2.54
22		21.4	18.6	40.0	7.8	2.40	.222	10.8	9.2	0	92	64	800	4	1.50	2.62
23		22.0	18.8	40.8	8.5	2.41	.219	11.0	9.7	0	92	66	600	4	1.50	2.63
24		24.1	19.6	43.7	8.5	2.49	.220	11.3	7.5	0	92	66	430	4	1.50	2.71
25		15.0	12.3	27.3	5.8	2.03	.187	10.9	....	0	....	......	280	4	1.50	2.22
26		12.5	13.3	25.8	5.3	4.45	.365	12.1	8.4	0	91	68	1,200	5	1.30	4.82
27		13.6	14.3	27.9	6.0	4.60	.382	12.1	8.6	0	91	68	1,000	5	......	4.96
28		12.8	13.0	25.8	5.0	4.45	.372	12.0	8.6	0	91	68	800	5	1.25	4.82
29		8.5	8.3	16.8	3.8	3.69	.318	11.6	6.2	0	92	68	600	5	1.40	4.01
30		5.8	6.2	12.0	2.8	3.10	.282	11.1	....	0	....	......	420	5	1.40	3.41
31	1	11.3	9.4	20.7	4.3	1.79	.171	10.5	1.5	0	93	70	210	5	1.60	1.96

CARBURETOR NO. 3.

[June 30, 1916; average barometer, 29.93 inches; gasoline, S. G., 0.7275.]

Run No.	Size, inch.	Left, inches.	Right, inches.	Height, inches water.	Pressure at Venturi inlet, inches water.	Pounds air per minute.	Pounds gas per minute.	Ratio.	Pressure drop across carburetor, inches mercury.	Pressure in box.	Inlet to carburetor.	Outlet from carburetor.	Engine revolutions per minute.	Throttle opening No.	Level in float chamber, inches.	Total pounds mixture per minute.
32	1	11.0	15.2	26.2	4.3	7.93	0.500	15.9	1.60	0	86	66	900	Full.	2.60	8.43
33	1	11.2	15.4	26.6	4.5	8.00	.565	14.2	1.50	0	86	66	800	Full.	2.50	8.57
34	1	12.3	16.6	28.9	4.3	8.30	.562	14.8	1.60	0	88	62	1,200	Full.	2.50	8.86
35	1	12.8	17.0	29.8	4.7	8.42	.557	15.1	1.50	0	84	58	1,400	Full.	2.50	8.98
36	1	12.0	16.3	28.3	4.8	8.25	.538	15.3	1.40	0	84	58	1,200	Full.	2.50	8.79
37	1	11.6	15.9	27.5	4.7	8.11	.518	15.6	1.30	0	84	57	1,000	Full.	2.60	8.63
38	1	9.8	13.8	23.6	4.0	7.56	.471	16.1	1.20	0	85	57	800	Full.	2.60	9.03
39	1	5.0	8.5	13.0	2.2	5.73	.378	15.2	.95	0	86	57	600	Full.	2.60	6.11
40		12.5	12.4	24.9	4.0	4.40	.317	13.9	.95	0	86	57	470	Full.	2.60	4.72
41		5.6	5.4	11.0	2.5	3.00	.225	13.3	.70	0	88	58	310	Full.	2.60	3.23
42		1.2	10.2	11.4	3.9	.28	.036	7.9	13.70	0	92	60	210	2	2.60	.32
43		5.9	15.7	21.6	6.9	.38	.032	11.7	15.20	0	94	60	345	2	2.60	.41
44		6.0	15.8	22.1	7.0	.38	.035	10.9	....	0	95	60	520	2	2.60	.41
45		6.3	15.8	22.1	7.0	.38	.035	10.9	....	0	96	62	650	2	2.60	.42
46		1.0	10.0	11.0	4.8	.20	.034	8.05	15.10	0	101	70	800	2	2.60	.31
47		4.8	14.3	19.1	5.8	.36	.033	10.8	14.60	0	94	64	1,000	2	2.60	.39
48		4.8	14.2	19.0	5.8	.36	.034	10.7	13.30	0	96	65	1,200	2	2.70	.39
49		4.6	14.1	20.7	5.8	.38	.034	11.1	13.70	0	97	65	1,400	2	2.70	.41
50		24.4	20.0	44.4	8.5	2.50	.204	12.3	9.00	0	90	58	1,400	3	2.60	2.70
51		27.0	21.9	48.9	9.3	2.60	.209	12.4	8.50	0	90	58	1,200	3	2.60	2.31
52		27.0	21.9	48.9	9.3	2.60	.210	12.4	9.20	0	90	57	1,000	3	2.60	2.81

TABLE II-VIII.—*Log of carburetor tests, Columbia University, June to August, 1916*—Continued.

CARBURETOR NO. 3—Continued.

Run No.	Venturi meter.				Pressure at Venturi inlet, inches water.	Pounds air per minute.	Pounds gas per minute.	Ratio.	Pressure drop across carburetor, inches mercury.	Pressure in box.	Temperature, °F.		Engine revolutions per minute.	Throttle opening No.	Level in float chamber, inches.	Total pounds mixture per minute.
	Size, inch.	Left, inches.	Right, inches.	Height, inches water.							Inlet to carburetor.	Outlet from carburetor.				
53	[illegible]	27.3	22.2	49.5	9.0	2.61	0.210	12.4	10.10	0	90	57	800	3	2.60	2.82
54	[illegible]	27.5	22.6	50.1	9.2	2.63	.203	13.0	9.70	0	89	57	600	3	2.60	2.83
55	[illegible]	20.3	16.6	36.9	7.2	2.32	.190	12.2	7.10	0	89	59	400	3	2.60	2.51
56	[illegible]	11.1	8.4	18.5	4.2	1.74	.146	12.0	4.20	0	90	61	250	3	2.60	1.89
57	[illegible]	4.1	3.7	7.8	1.8	2.54	.194	13.1	1.50	0	89	62	275	4	2.60	2.73
58	[illegible]	7.3	7.1	14.4	3.0	3.42	.259	13.2	2.30	0	89	60	400	4	2.60	3.68
59	[illegible]	14.0	14.2	28.2	5.7	4.62	.321	14.4	3.80	0	88	60	600	4	2.60	4.94
60	[illegible]	8.3	19.2	37.5	6.0	5.29	.356	14.8	5.60	0	88	50	800	4	2.60	5.65
61	[illegible]	16.5	16.8	33.3	6.1	4.99	.319	15.6	5.20	0	88	60	1,000	4	2.50	5.31
62	[illegible]	19.1	19.8	38.9	7.3	5.35	.405	13.2	6.40	0	88	58	1,200	4	2.50	5.76
63	[illegible]	19.7	20.5	40.2	7.6	5.48	.366	16.0	6.20	0	88	59	1,400	4	2.50	5.85
64	1	8.7	12.5	21.2	3.7	7.25	.444	16.3	3.40	0	88	60	1,410	5	2.60	7.69
65	1	8.3	11.8	20.1	3.2	7.00	.500	14.0	3.70	0	88	59	1,200	5	2.50	7.50
66	1	8.3	11.7	20.0	3.4	7.00	.447	15.7	3.40	0	88	60	1,000	5	2.50	7.46
67	1	7.3	10.6	17.9	3.4	6.68	.424	15.7	3.30	0	88	60	800	5	2.50	7.10
68	[illegible]	21.4	15.3	36.7	6.8	5.20	.367	14.2	2.00	0	88	60	600	5	2.50	5.57
69	[illegible]	12.5	5.8	19.3	3.9	3.91	.282	13.5	1.20	0	89	60	400	5	2.50	3.09
70	2	26.3	24.2	50.5	9.8	2.57	.227	11.3	1.00	0	89	60	300	5	2.60	2.80
71	1	8.3	11.8	20.1	3.5	7.00	.510	13.7	3.75	0	88	59	1,200	5	2.50	7.51

CARBURETOR No. 4.

[July 1, 1916; average barometer, 29.86 inches; gasoline, S. G., 0.7275.]

72	1	9.8	13.5	23.3	......	7.55	0.490	13.4	2.60	0	84	56	1,000	Full.	1.50	8.04
73	[illegible]	13.0	5.9	18.9	......	3.86	.240	16.1	.70	0	86	59	410	Full.	1.70	4.10
74	[illegible]	24.3	18.1	42.4	......	5.55	.340	16.3	1.20	0	85	58	600	Full.	1.60	5.89
75	1	8.8	12.3	21.1	......	7.22	.460	15.7	2.30	0	85	58	800	Full.	1.45	7.70
76	1	9.7	13.4	23.1	......	7.52	.485	15.5	2.60	0	85	58	1,000	Full.	1.40	8.01
77	1	9.6	13.2	22.8	......	7.50	.485	15.5	2.60	0	86	58	1,200	Full.	1.35	7.99
78	1	9.7	13.4	23.1	......	7.52	.485	15.5	2.65	0	86	58	1,400	Full.	1.35	8.01

[July 3, 1916; average barometer, 29.49 inches.]

79	[illegible]	3.1	4.6	7.7	2.2	1.19	0.064	18.6	12.4	0	88	59	1,200	2	1.80	1.25
80	[illegible]	3.6	2.1	5.7	1.9	1.03	.051	20.0	13.9	0	90	62	1,000	2	1.80	1.08
81	[illegible]	1.8	3.6	5.4	1.5	.95	.047	20.2	15.5	0	90	62	800	2	1.80	1.00
82	[illegible]	2.1	3.8	5.9	1.7	.98	.053	18.4	15.5	0	90	62	600	2	1.80	1.03
83	[illegible]	2.1	3.8	5.9	1.6	.98	.049	20.0	15.0	0	90	62	400	2	1.80	1.03
84	[illegible]	2.1	3.8	5.9	1.6	.98	.048	20.7	12.8	0	90	63	320	2	1.75	1.03
85	[illegible]	14.9	14.8	29.7	6.2	2.12	.139	15.3	11.3	0	88	58	1,200	3	1.70	2.26
86	[illegible]	15.5	15.3	30.8	6.4	2.13	.138	15.4	12.1	0	88	58	1,000	3	1.65	2.27
87	[illegible]	15.4	15.3	30.7	6.2	2.13	.136	15.7	12.0	0	89	59	800	3	1.70	2.27
88	[illegible]	15.2	15.5	30.7	6.2	2.13	.137	15.6	12.0	0	89	59	600	3	1.70	2.27
89	[illegible]	13.6	13.8	27.4	5.5	2.02	.133	15.2	9.8	0	90	60	420	3	1.70	2.15
90	[illegible]	10.8	11.4	22.2	5.0	1.84	.133	13.8	7.0	0	90	62	320	3	1.70	1.97
91	[illegible]	9.7	9.5	19.2	4.4	1.73	.102	16.9	8.3	0	82	57	305	3	1.75	1.83
92	[illegible]	13.0	5.2	18.2	3.8	3.81	.227	16.8	8.9	0	89	61	1,200	4	1.65	4.04
93	[illegible]	13.3	5.4	18.7	3.6	3.90	.230	16.9	9.4	0	90	62	1,000	4	1.65	4.13
94	[illegible]	13.3	5.9	19.7	3.5	3.97	.234	16.3	9.9	0	90	60	800	4	1.65	4.20
95	[illegible]	12.5	4.6	17.1	3.4	3.71	.222	16.7	7.9	0	90	61	600	4	1.65	4.02
96	[illegible]	10.0	2.1	12.1	2.6	3.13	.188	16.7	4.5	0	91	62	420	4	1.65	3.32
97	[illegible]	8.2	0.2	8.4	1.9	2.64	.165	16.0	2.3	0	91	64	330	4	1.65	2.81
98	[illegible]	26.7	20.0	46.7	8.6	5.75	.343	16.8	6.2	0	91	62	1,200	5	1.50	6.09
99	[illegible]	26.4	19.6	46.0	9.0	5.70	.357	16.0	6.2	0	92	62	1,000	5	1.50	6.06
100	[illegible]	25.3	18.5	43.8	8.0	5.60	.347	16.2	5.7	0	92	64	800	5	1.50	5.95
101	[illegible]	20.0	12.7	32.7	6.4	4.90	.290	16.8	4.0	0	93	65	600	5	1.50	5.19
102	[illegible]	12.2	4.4	16.6	3.4	3.64	.226	16.1	1.9	0	94	65	420	5	1.60	3.87
103	[illegible]	22.5	21.2	43.7	8.4	2.49	.171	14.6	1.0	0	93	65	280	5	1.60	2.66

Table II-VIII.—*Log of carburetor tests, Columbia University, June to August, 1916*—Continued.

CARBURETOR NO. 10.

[July 5, 1916; average barometer, 29.82 inches; gasoline, S. G., 0.7275.]

Run No.	Venturi meter.				Pressure at Venturi inlet, inches water.	Pounds air per minute.	Pounds gas per minute.	Ratio.	Pressure drop across carburetor, inches mercury.	Pressure in box.	Temperature, °F.		Engine revolutions per minute.	Throttle opening No.	Level in float chamber, inches.	Total pounds mixture per minute.
	Size, inch.	Left, inches.	Right, inches.	Height, inches water.							Inlet to carburetor.	Outlet from carburetor.				
104	1	5.7	8.0	13.7	2.3	5.90	0.372	15.3	1.4	0	83	57	600	1	2.00	6.27
105	1	9.8	12.8	22.6	3.5	7.40	.465	15.9	2.2	0	84	57	800	1	1.95	7.87
106	1	10.5	13.5	24.0	3.9	7.63	.480	15.9	2.5	0	83	56	1,000	1	1.95	8.11
107	1	10.7	13.7	24.4	3.9	7.64	.490	15.6	2.5	0	82	56	1,200	1	1.95	8.13
108	[illegible]	15.8	15.7	31.5	5.8	4.85	.266	18.2	.95	0	82	58	600	1	1.95	5.12
109	[illegible]	10.7	10.3	21.0	4.2	4.07	.210	19.4	.70	0	82	58	400	1	2.00	4.28
110	[illegible]	7.5	7.4	14.9	3.6	1.53	.080	19.1	.20	0	84	62	145	1	2.05	1.61
111	[illegible]	17.0	14.6	31.6	5.8	2.15	.130	16.5	.35	0	83	60	220	1	2.10	2.28
112	[illegible]	3.3	2.9	6.2	1.8	1.01	.068	17.4	12.8	0	86	58	270	2	2.10	1.07
113	[illegible]	24.0	25.7	49.7	14.6	.545	.042	13.0	6.3	0	87	60	125	2	2.10	.59
114	[illegible]	3.2	2.8	6.0	1.5	.985	.056	17.8	15.2	0	86	58	420	2	2.10	1.05
115	[illegible]	6.6	5.7	12.3	3.1	1.40	.077	18.3	7.4	0	87	60	240	3	2.10	1.48
116	[illegible]	8.2	7.1	15.3	3.5	1.55	.100	15.5	11.6	0	87	58	390	3	2.15	1.65
117	[illegible]	9.2	7.9	17.1	3.9	1.64	.090	18.2	13.5	0	87	58	500	3	2.15	1.73
118	[illegible]	9.2	8.0	17.2	3.9	1.64	.095	17.3	13.9	0	87	58	600	3	2.15	1.74

[July 6, 1916; average barometer, 29.99 inches.]

119	[illegible]	13.3	11.4	24.7	5.3	1.94	0.110	17.6	2.9	0	82	58	220	4	2.10	2.05
120	[illegible]	26.0	22.1	48.1	9.0	2.59	.172	15.1	6.0	0	82	56	400	4	2.10	2.76
121	[illegible]	6.0	5.2	11.2	2.6	3.16	.195	16.2	8.9	0	82	55	500	4	2.10	3.36
122	[illegible]	7.0	6.2	13.2	2.8	3.25	.215	15.1	10.2	0	81	54	600	4	2.10	3.47
123	[illegible]	7.3	6.5	13.8	2.8	3.35	.215	15.6	11.1	0	82	54	700	4	2.05	3.57
124	[illegible]	7.5	6.7	14.2	2.9	3.39	.220	15.4	11.7	0	82	53	800	4	2.05	3.61
125	[illegible]	7.3	6.5	13.8	2.8	3.33	.215	15.6	10.8	0	84	55	1,000	4	2.05	3.57
126	[illegible]	15.3	14.9	30.8	5.6	4.80	.319	15.1	4.8	0	85	57	600	5	2.00	5.12
127	[illegible]	11.8	11.1	22.9	4.6	4.25	.280	15.2	3.7	0	85	58	710	5	2.00	4.53
128	[illegible]	7.1	6.4	13.5	3.2	3.30	.200	16.5	1.9	0	85	59	360	5	2.00	3.50
129	[illegible]	19.5	19.5	39.0	7.0	5.33	.375	14.2	6.8	0	85	56	820	5	2.00	5.71
130	1	4.9	6.9	11.8	2.0	5.50	.370	14.9	6.8	0	84	56	900	5	2.00	5.87
131	1	4.2	6.1	10.3	1.9	5.15	.352	14.7	6.2	0	85	56	700	5	2.00	5.50

CARBURETOR NO. 2.

[July 10, 1916; average barometer, 29.92 inches; gasoline, S. G., 0.7275.]

132	[illegible]	7.7	6.3	14.0	3.4	1.49	0.124	12.1	9.3	0	90	63	280	1	1.95	1.61
133	[illegible]	9.0	7.5	16.5	4.0	1.61	.125	12.9	13.5	0	89	60	450	1	1.90	1.74
134	[illegible]	9.3	7.7	17.0	4.0	1.64	.127	13.0	13.3	0	88	58	820	1	1.90	1.77
135	[illegible]	9.3	7.7	17.0	4.0	1.64	.132	12.5	9.35	0	88	58	750	1	1.90	1.77
136	[illegible]	9.1	7.6	16.7	4.0	1.63	.128	12.8	9.20	0	88	60	620	1	1.90	1.76
137	[illegible]	9.0	7.5	16.5	3.9	1.62	.124	13.0	....	0	89	61	620	1	1.90	1.74
138	[illegible]	8.8	7.3	16.1	3.9	1.60	.125	12.8	13.4	0	89	61	750	1	1.90	1.73
139	[illegible]	5.5	4.3	9.8	2.5	2.85	.311	9.2	1.1	0	88	60	295	2	1.90	3.16
140	[illegible]	15.9	14.9	30.8	5.8	4.80	.375	12.8	1.7	0	88	64	550	2	1.85	5.18
141	[illegible]	9.3	8.2	17.5	3.6	3.75	.348	10.8	1.35	0	88	63	420	2	1.90	4.10
142	1	7.6	9.8	17.4	2.9	6.60	.425	15.5	2.20	0	88	66	750	2	1.90	7.03
143	1	9.3	11.8	21.1	3.6	7.20	.436	16.5	2.40	0	88	66	930	2	1.90	7.64
144	1	9.4	11.9	21.3	3.6	7.20	.436	16.5	2.40	0	88	66	1,000	2	1.90	7.64
145	[illegible]	16.6	14.2	30.8	6.6	2.14	.150	14.2	3.45	0	88	66	275	3	1.95	2.29
146	[illegible]	5.7	4.5	10.2	2.3	2.87	.163	17.6	6.00	0	89	70	430	3	1.85	3.03
147	[illegible]	7.7	6.5	14.2	3.2	3.38	.173	19.5	8.80	0	88	70	610	3	1.85	3.55
148	[illegible]	8.6	7.5	16.1	3.5	3.60	.173	20.8	10.2	0	88	70	750	3	1.95	3.77
149	[illegible]	8.6	7.5	16.1	3.5	3.60	.172	21.0	10.5	0	88	69	920	3	1.95	3.77
150	[illegible]	4.7	3.4	8.1	2.0	2.59	.154	16.8	2.0	0	89	66	280	4	1.95	2.74
151	[illegible]	8.5	7.4	15.9	3.5	3.58	.175	20.4	3.3	0	89	69	420	4	1.90	3.67
152	4	12.6	11.5	24.1	4.6	4.32	.186	23.2	4.4	0	88	70	570	4	1.90	4.51
153	4	16.9	16.2	33.1	6.1	4.99	.197	25.4	6.0	0	89	70	730	4	1.90	5.19
154	4	18.8	18.2	37.0	7.0	5.23	.202	25.9	6.8	0	89	70	900	4	1.90	5.43
155	4	18.6	18.1	36.7	7.7	5.22	.206	25.4	6.8	0	89	70	1,900	4	1.95	5.43
156	[illegible]	21.4	18.3	39.7	7.7	2.39	.162	14.7	1.3	0	89	66	265	5	1.95	2.55
157	[illegible]	9.2	8.0	17.2	3.7	3.72	.191	19.5	1.7	0	89	68	420	5	1.90	3.91
158	[illegible]	17.5	17.0	34.5	6.8	5.10	.211	24.2	2.6	0	88	69	600	5	1.90	5.31
159	1	6.0	8.2	14.5	2.7	6.05	.223	27.2	9.1	0	88	70	750	5	1.90	6.27
160	1	7.7	10.0	17.7	3.0	6.68	.231	28.9	3.6	0	88	70	900	5	1.90	6.91
161	1	8.0	10.0	18.2	3.1	6.71	.234	28.7	3.7	0	88	70	1,000	5	1.90	6.94
162	1	8.0	10.2	18.2	3.1	6.71	.234	28.7	3.7	0	88	70	1,100	5	1.90	6.94

Table II-VIII.—*Log of carburetor tests, Columbia University, June to August, 1916*—Continued.

CARBURETOR NO. 7.

[July 11, 1916; barometer, 29.90 inches; gasoline, S.G., 0.7275.]

Run No.	Venturi meter. Size, inch.	Venturi meter. Left, inches.	Venturi meter. Right, inches.	Venturi meter. Height, inches water.	Pressure at Venturi inlet, inches water.	Pounds air per minute.	Pounds gas per minute.	Ratio.	Pressure drop across carburetor, inches mercury.	Pressure in box.	Temperature, °F. Inlet to carburetor.	Temperature, °F. Outlet from carburetor.	Engine revolutions per minute.	Throttle opening No.	Level in float chamber, inches.	Total pounds mixture per minute.
163	1	8.3	10.4	18.7	3.2	6.84	0.517	13.2	3.0	0	87	64	830	1	0.95	7.36
164	1	8.6	10.8	19.4	3.2	6.93	.485	14.3	3.2	0	87	66	920	1	.95	7.42
165	1	9.1	11.4	20.6	3.4	7.10	.522	13.6	3.3	0	88	66	1,000	1	.95	7.62
166	1	9.0	11.3	20.3	3.4	7.10	.533	13.3	3.3	0	88	65	1,100	1	.90	7.63
167	1	8.8	11.1	19.9	3.3	7.00	.533	13.15	3.2	0	88	66	920	1	.95	7.53
168	1	5.4	7.2	12.6	2.1	5.64	.440	12.8	2.0	0	88	66	630	1	.95	6.08
169	½	11.3	10.1	21.4	4.1	4.11	.320	12.75	1.1	0	88	66	430	1	.95	4.43
170	½	5.5	4.2	9.7	2.3	2.84	.231	12.3	.55	0	88	66	280	1	.95	3.07
171	½	5.6	4.7	10.3	2.8	1.28	.136	9.4	9.9	0	90	64	265	2	1.00	1.42
172	½	6.1	5.1	11.2	2.9	1.33	.145	9.15	13.3	0	90	63	400	2	1.00	1.48
173	½	6.4	5.4	11.8	3.2	1.38	.158	8.75	15.0	0	90	60	520	2	1.00	1.54
174	½	6.4	5.4	11.8	3.2	1.36	.152	9.10	15.0	0	90	60	640	2	.95	1.53
175	½	6.2	5.2	11.4	3.1	1.35	.148	9.15	14.0	0	90	60	810	2	1.00	1.50
176	½	13.0	11.0	24.0	7.3	1.92	.214	8.83	4.7	0	90	65	260	3	1.00	2.13
177	½	19.3	16.3	35.6	7.3	2.28	.240	9.50	7.9	0	90	63	390	3	.95	2.52
178	½	24.9	21.2	46.1	9.0	2.54	.232	10.9	10.7	0	90	64	520	3	1.00	2.79
179	½	5.4	4.1	9.5	2.3	2.81	.219	12.8	12.2	0	90	64	640	3	1.00	3.03
180	½	5.6	4.3	9.9	2.3	2.84	.209	13.6	13.7	0	90	63	800	3	.95	3.05
181	½	5.3	4.1	9.4	2.2	2.81	.236	11.9	12.4	0	90	63	1,000	3	.95	3.05
182	½	5.3	4.0	9.3	2.1	2.80	.219	12.8	.4	0	92	68	270	4	1.00	3.02
183	½	9.8	8.6	18.4	3.6	3.83	.296	13.4	.75	0	91	66	400	4	1.00	4.13
184	½	15.9	15.1	31.0	5.8	4.85	.363	13.4	1.1	0	90	66	520	4	.95	4.21
185	½	22.3	22.0	44.3	8.0	5.65	.432	13.1	1.7	0	90	66	630	4	.95	6.08
186	1	8.3	10.4	18.7	3.1	6.80	.500	13.6	2.2	0	90	66	750	4	.90	7.30
187	1	9.8	12.4	22.2	3.6	7.38	.563	13.1	2.6	0	90	66	900	4	.90	7.94
188	1	10.3	12.9	23.2	3.8	7.53	.518	13.0	2.7	0	90	66	1,000	4	.90	8.11
189	1	10.0	12.7	22.7	3.8	7.52	.578	13.0	2.7	0	91	66	1,100	4	.90	8.10
190	½	20.8	17.5	38.3	7.7	2.35	.215	10.95	1.8	0	92	67	275	5	.95	2.57
191	½	7.3	5.9	13.2	2.6	3.28	.271	12.10	3.2	0	92	67	400	5	.95	3.55
192	½	11.0	9.9	20.9	4.3	4.07	.298	13.65	4.7	0	92	67	520	5	.95	4.37
193	½	13.8	12.9	26.7	5.3	4.58	.334	13.75	6.4	0	92	66	650	5	.95	4.91
194	½	16.3	15.5	31.8	6.2	4.88	.360	13.3	7.7	0	92	65	800	5	.90	5.25
195	½	16.5	15.7	32.2	6.2	4.92	.368	13.4	8.0	0	92	64	......	5	.90	5.29

CARBURETOR NO. 8.

[July 12, 1916; average barometer, 29.86 inches; gasoline, S. G, 0.7275.]

Run No.	Size, inch.	Left, inches.	Right, inches.	Height, inches water.	Pressure at Venturi inlet, inches water.	Pounds air per minute.	Pounds gas per minute.	Ratio.	Pressure drop across carburetor, inches mercury.	Pressure in box.	Inlet to carburetor.	Outlet from carburetor.	Engine revolutions per minute.	Throttle opening No.	Level in float chamber, inches.	Total pounds mixture per minute.
196	1	9.9	12.3	22.2	3.6	7.40	0.462	16.0	1.5	0	86	64	800	1	1.75	7.86
197	1	11.6	14.2	25.8	4.2	7.90	.500	15.8	1.6	0	86	64	920	1	1.80	8.40
198	1	11.9	14.6	26.5	4.3	8.00	.511	15.6	1.7	0	86	64	1,010	1	1.80	8.01
199	1	12.1	14.9	27.0	4.3	8.05	.518	15.5	1.7	0	86	64	1,100	1	1.80	8.57
200	1	12.4	15.1	27.5	4.3	8.13	.524	15.5	1.7	0	86	64	1,175	1	1.80	8.65
201	1	12.7	15.6	28.3	4.5	8.20	.533	15.9	1.7	0	86	64	1,400	1	1.80	8.73
202	1	14.3	17.5	31.8	5.2	8.65	.572	15.1	1.9	0	87	64	1,600	1	1.80	9.22
203	1	7.5	9.7	17.2	2.9	6.57	.418	15.7	1.3	0	88	66	720	1	1.80	6.09
204	1	5.2	7.0	12.2	2.1	5.56	.348	16.0	1.0	0	88	66	590	1	1.80	5.91
205	½	12.1	10.7	22.8	4.6	4.25	.276	15.4	9.8	0	88	66	450	1	1.80	4.53
206	½	18.8	14.0	33.0	6.5	2.22	.153	14.5	.8	0	88	67	230	1	1.80	2.37
207	½	7.7	6.2	13.9	3.0	3.35	.233	14.4	.8	0	88	66	345	1	1.80	2.37
208	1	15.9	19.2	35.1	5.8	9.00	.600	15.0	2.1	0	88	64	1,800	1	1.80	3.60
209	½	7.3	4.7	12.0	3.1	1.38	.078	17.7	13.8	0	89	66	420	2	1.80	1.46
210	½	7.4	4.8	12.2	3.1	1.59	.081	17.2	15.0	0	90	66	570	2	1.80	1.47
211	½	6.8	4.3	11.0	3.1	3.14	.074	18.1	12.0	0	90	68	360	2	1.80	1.42
212	½	6.2	3.8	10.0	2.8	1.27	.067	19.0	8.8	0	90	69	240	2	1.80	1.34
213	½	23.0	18.0	41.0	8.0	2.42	.177	13.7	5.7	0	90	67	370	3	1.80	2.59
214	½	14.5	10.9	25.4	5.3	1.96	.132	14.8	3.4	0	90	68	250	3	1.80	2.09
215	½	6.2	4.3	11.0	2.6	3.00	.205	14.6	8.8	0	90	66	510	3	1.80	3.20
216	½	6.8	5.5	12.3	2.9	3.16	.214	14.1	10.8	0	90	64	650	3	1.80	3.37
217	½	7.3	5.9	13.2	2.9	3.27	.222	14.7	11.9	0	90	64	830	3	1.80	3.49
218	½	7.0	5.6	12.6	2.8	3.20	.218	14.7	11.1	0	90	64	1,000	3	1.80	3.42
219	½	2.0	15.9	35.9	7.2	2.27	.154	14.7	1.5	0	90	68	250	4	1.80	2.42
220	½	6.3	4.8	11.1	2.6	3.00	.202	14.9	2.0	0	90	68	350	4	1.80	3.20
221	½	10.5	9.3	19.8	4.0	3.97	.276	14.4	2.4	0	91	68	426	4	1.80	4.25
222	½	15.4	14.4	20.8	5.7	4.76	.324	14.7	6.4	0	91	65	700	4	1.80	5.08
223	½	11.5	16.5	34.0	6.4	5.04	.376	13.4	7.4	0	91	65	1,000	4	1.80	5.42
224	1	4.2	5.8	10.0	1.6	5.08	.329	15.4	8.1	0	92	......	1,200	4	1.80	5.41
225	1	4.2	5.8	10.0	1.6	5.08	.328	15.4	8.1	0	92	......	1,400	4	1.80	1.80
226	½	10.8	7.8	18.6	3.5	1.70	.104	16.4	6.3	0	92	68	255	5	1.80	1.81

TABLE II-VIII.—*Log of carburetor tests, Columbia University, June to August, 1916*—Continued.

CARBURETOR NO. 3—Continued.

Run No.	Venturi meter. Size, inch.	Venturi meter. Left, inches.	Venturi meter. Right, inches.	Venturi meter. Height, inches water.	Pressure at Venturi inlet, inches water.	Pounds air per minute.	Pounds gas per minute.	Ratio.	Pressure drop across carburetor, inches mercury.	Pressure in box.	Temperature, °F. Inlet to carburetor.	Temperature, °F. Outlet from carburetor.	Engine revolutions per minute.	Throttle opening No.	Level in float chamber, inches.	Total pounds mixture per minute.
227	½	12.8	9.4	22.2	4.1	1.85	.120	15.4	8.5	0	92	68	330	5	1.80	1.97
228	½	14.2	10.7	24.9	4.5	1.94	.128	15.1	10.9	0	92	68	430	5	1.80	2.07
229	½	19.7	11.0	25.7	4.6	1.98	.131	15.0	13.0	0	92	67	530	5	1.80	2.11
230	½	15.2	11.5	26.7	4.7	2.02	.134	15.1	13.4	0	92	66	600	5	1.80	2.15
231	½	14.3	10.6	24.9	4.5	1.04	.125	15.5	13.25	0	92	66	730	5	1.80	2.07
232	¾	5.5	4.1	9.6	1.8	2.80	.185	15.1	10.1	0	94	68	530	5	1.80	2.96
233	¾	5.8	4.3	10.1	1.9	2.89	.192	15.0	11.2	0	93	66	630	5	1.80	3.08
234	¾	5.9	4.5	10.4	1.9	2.92	.192	15.2	11.4	0	93	66	710	5	1.80	3.11

CARBURETOR No. 6.

[July 13, 1916; average barometer, 29.80 inches; gasoline, S.G., 0.7275.

Run No.	Size, inch.	Left, inches.	Right, inches.	Height, inches water.	Pressure at Venturi inlet, inches water.	Pounds air per minute.	Pounds gas per minute.	Ratio.	Pressure drop across carburetor, inches mercury.	Pressure in box.	Inlet to carburetor.	Outlet from carburetor.	Engine revolutions per minute.	Throttle opening No.	Level in float chamber, inches.	Total pounds mixture per minute.
235	1	11.1	13.7	4.0	24.8	7.70	0.490	15.7	1.8	0	93	66	1,000	1	1.85	7.19
236	1	11.8	14.6	4.3	26.4	8.00	.485	16.5	1.8	0	93	66	1,200	1	1.90	8.49
237	1	13.0	15.9	4.8	28.9	8.30	.513	16.2	1.8	0	92	66	1,600	1	1.90	8.81
238	1	9.5	11.9	21.4	3.5	7.25	.494	16.3	1.5	0	92	66	800	1	1.90	7.69
239	1	5.3	7.0	12.3	3.8	5.70	.348	16.4	1.0	0	92	66	600	1	1.90	6.05
240	1	3.6	5.0	8.6	4.1	4.72	.296	16.0	.7	0	92	66	500	1	1.90	6.02
241	1	2.4	3.7	6.1	4.3	4.00	.243	16.4	.5	0	92	66	400	1	1.90	4.24
242	¾	4.9	3.3	8.2	1.9	2.61	.182	14.3	.5	0	92	66	260	1	1.95	2.79
243	½	4.7	2.5	7.2	2.0	1.08	.064	16.9	10.5	0	93	66	220	2	1.90	1.14
244	½	4.9	2.6	7.5	2.0	1.10	.068	16.2	13.2	0	92	66	340	2	1.90	1.17
245	½	5.0	2.7	7.7	2.0	1.12	.068	16.5	14.4	0	93	66	420	2	1.90	1.19
246	½	7.7	5.1	12.8	3.3	1.42	.086	16.5	8.1	0	92	66	250	3	1.85	1.49
247	½	8.4	5.7	14.1	3.4	1.50	.095	15.8	9.9	0	92	66	320	3	1.85	1.60
248	½	9.7	6.7	16.4	3.9	1.50	.098	16.4	12.3	0	92	66	420	3	1.80	1.70
249	½	9.8	6.8	16.6	3.9	1.62	.098	16.5	13.3	0	92	66	520	3	1.80	1.72

[July 14, 1916; average barometer, 29.96 inches.]

Run No.	Size, inch.	Left, inches.	Right, inches.	Height, inches water.	Pressure at Venturi inlet, inches water.	Pounds air per minute.	Pounds gas per minute.	Ratio.	Pressure drop across carburetor, inches mercury.	Pressure in box.	Inlet to carburetor.	Outlet from carburetor.	Engine revolutions per minute.	Throttle opening No.	Level in float chamber, inches.	Total pounds mixture per minute.
250	½	13.2	9.5	22.7	4.8	1.86	0.121	15.3	11.5	0	86	61	420	4	1.85	1.98
251	½	11.3	8.0	10.3	4.3	1.73	.110	15.7	9.2	0	87	63	320	4	1.85	1.84
252	½	9.2	6.1	15.3	3.7	1.55	.094	16.5	6.3	0	87	64	220	4	1.85	1.65
253	½	14.0	10.2	24.2	5.2	1.92	.112	17.2	13.0	0	87	62	560	4	1.85	2.03
254	½	13.9	10.1	24.0	5.2	1.92	.125	15.3	12.8	0	88	60	720	4	1.85	2.05
255	½	14.0	10.2	24.2	5.2	1.92	.138	13.9	12.8	0	88	60	560	4	1.85	2.06
256	½	14.0	10.2	24.2	5.2	1.92	.136	14.1	12.8	0	88	60	560	4	1.85	2.06
257	¾	8.2	6.5	14.7	3.1	3.47	.233	14.9	8.8	0	87	60	560	5	1.90	3.70
258	¾	9.2	7.5	16.7	3.4	3.65	.240	15.2	10.5	0	88	59	720	5	1.90	3.89
259	¾	9.2	7.5	16.7	3.4	3.65	.246	14.9	10.5	0	88	59	920	5	1.90	3.90
260	¾	8.5	6.9	15.4	3.2	3.62	.250	14.1	9.5	0	88	59	1,100	5	1.90	3.77

[July 21, 1916.]

Run No.	Size, inch.	Left, inches.	Right, inches.	Height, inches water.	Pressure at Venturi inlet, inches water.	Pounds air per minute.	Pounds gas per minute.	Ratio.	Pressure drop across carburetor, inches mercury.	Pressure in box.	Inlet to carburetor.	Outlet from carburetor.	Engine revolutions per minute.	Throttle opening No.	Level in float chamber, inches.	Total pounds mixture per minute.
261	½	8.5	9.5	18.0	6.6	1.66	0.122	13.6	1.85	0	88	66	200	5	1.90	1.78
262	½	14.5	15.0	29.5	10.4	2.10	.140	15.0	3.00	0	88	66	250	5	1.90	2.24
263	½	19.4	19.3	38.7	7.4	2.35	.182	12.3	4.50	0	88	64	345	5	1.95	2.53
264	¾	7.3	5.0	12.3	6.5	3.13	.222	14.1	7.00	0	88	64	480	5	2.00	3.35
265	¾	7.6	5.3	12.9	6.5	3.23	.226	14.4	8.00	0	90	64	560	5	2.00	3.46
266	¾	5.6	3.3	8.9	6.9	2.38	.168	14.2	4.00	0	88	66	340	5	1.95	2.55
267	¾	4.0	1.7	5.7	7.2	2.18	.155	14.1	2.80	0	90	66	250	5	1.90	2.34
268	¾	6.7	4.4	11.2	6.9	3.00	.212	14.2	.60	0	90	66	290	1	2.00	3.21
269	¾	8.4	6.1	14.5	6.8	3.43	.248	13.8	.80	0	90	66	350	1	1.95	3.68
270	¾	13.8	11.6	25.4	6.0	4.42	.308	14.4	1.00	0	90	66	450	1	1.95	4.72
271	¾	21.8	20.1	41.9	7.5	5.50	.368	14.9	1.20	0	90	66	580	1	1.95	5.87

TABLE II-VIII.—*Log of carburetor tests, Columbia University, June to August, 1916*—Continued.

CARBURETOR NO 5.

[July 29, 1916; average barometer, 30.30 inches; gasoline, S. G., equals 0.7175.]

Run No.	Venturi meter. Size, inch.	Left, inches.	Right, inches.	Height, inches, water.	Pressure at Venturi inlet, inches water.	Pounds air per minute.	Pounds gas per minute.	Ratio.	Pressure drop across carburetor, inches mercury.	Pressure in box.	Temperature, °F. Inlet to carburetor.	Outlet from carburetor.	Engine revolutions per minute.	Throttle opening No.	Level in float chamber, inches.	Total pounds mixture per minute.
272	¾	12.5	15.5	28.0	5.8	2.07	0.113	18.3	1.00	0	78	58	210	1	2.15	2.18
273	¾	10.5	7.6	18.1	3.6	3.80	.198	19.2	1.00	0	78	53	390	1	2.15	4.00
274	¾	18.6	16.2	34.8	6.6	5.11	.284	18.02	1.20	0	78	53	540	1	2.15	5.39
275	1	9.0	9.8	18.8	3.2	6.82	.392	17.40	1.40	0	78	53	700	1	2.15	7.21
276	1	12.7	14.1	26.8	4.5	8.00	.487	16.45	1.70	0	80	58	880	1	2.15	8.49
277	1	13.1	14.6	27.7	5.4	8.15	.512	15.92	1.70	0	81	54	1,050	1	2.15	8.66
278	1	13.5	14.9	28.4	4.6	8.21	.527	15.70	1.70	0	81	55	1,250	1	2.15	8.90
279	¾	5.6	5.3	10.9	3.7	.277	.038	7.30	12.00	0	81	62	160	2	2.15	.313
280	¾	5.9	5.5	11.4	3.9	.282	.037	7.62	13.10	0	81	58	200	2	2.15	.319
281	¾	6.1	5.9	12.0	5.5	.290	.037	7.83	14.00	0	82	53	260	2	2.15	.327
282	¾	6.0	5.8	11.8	4.5	.288	.036	8.57	11.10	0	82	53	125	2	2.15	.324
283	¾	16.3	18.5	34.8	7.1	2.25	.138	16.32	1.00	0	82	56	240	3	2.15	2.39
284	¾	9.4	6.4	15.8	3.8	3.56	.188	18.97	1.10	0	82	54	380	3	2.15	3.75
285	¾	19.5	17.4	36.9	7.1	5.20	.299	17.40	1.20	0	82	55	550	3	2.15	5.50
286	1	9.3	10.1	19.4	3.2	6.92	.412	16.80	1.50	0	82	56	730	3	2.15	7.33
287	1	12.3	13.5	25.8	4.2	7.00	.502	15.76	1.70	0	82	56	900	3	2.15	8.40
288	1	12.5	13.9	26.4	4.2	8.00	.516	15.50	1.70	0	82	58	1,060	3	2.15	8.52
289	¾	10.3	7.6	17.9	3.7	3.77	.220	17.15	1.00	0	82	60	400	3	2.15	3.99
290	¾	10.5	13.8	24.3	5.3	1.94	.113	17.15	1.00	0	82	60	205	4	2.15	2.06
291	¾	18.0	15.5	33.5	6.4	5.00	.272	18.40	1.80	0	82	60	550	4	2.15	5.27
292	1	7.8	8.4	16.2	2.7	6.40	.377	16.98	2.50	0	82	60	740	4	2.15	6.77
293	1	9.7	10.5	20.2	3.3	7.08	.422	16.80	3.00	0	82	60	900	4	2.15	7.50
294	1	10.0	11.0	21.0	3.3	7.25	.440	16.47	3.10	0	84	60	1,000	4	2.15	7.69
295	¾	9.3	6.5	15.8	3.3	3.56	.184	19.30	1.30	0	84	64	380	4	2.15	3.74
296	¾	6.7	4.0	10.7	2.6	2.93	.158	18.52	1.20	0	84	60	300	4	2.15	3.09
297	1	10.1	11.1	21.1	3.4	7.26	.430	16.85	3.20	0	84	60	1,100	4	2.15	7.69
298	¾	8.8	12.3	21.1	4.6	1.82	.106	17.18	3.10	0	84	68	230	5	2.15	1.92
299	¾	14.7	17.2	31.2	6.4	2.16	.120	18.00	4.30	0	84	64	290	5	2.15	2.28
300	¾	19.8	21.6	41.4	8.0	2.43	.138	17.60	5.70	0	84	60	380	5	2.15	2.57
301	¾	·6.8	4.0	10.8	2.3	2.94	.149	19.70	8.40	0	84	60	500	5	2.15	3.09
302	¾	7.3	4.5	11.8	2.6	3.12	.154	20.30	9.30	0	84	60	600	5	2.15	3.27
303	¾	7.7	4.8	12.5	2.8	3.18	.162	19.65	10.30	0	84	60	720	5	2.15	3.34
304	¾	4.0	8.1	12.1	3.1	1.39	.082	16.95	2.10	0	84	62	160	5	2.15	1.47
305	¾	4.8	8.9	13.7	3.3	1.47	.083	17.70	2.20	0	84	61	180	5	2.15	1.55
306	¾	5.0	9.0	14.0	3.4	1.50	.084	17.70	2.20	0	84	61	160	5	2.15	1.58
307	¾	0.5	5.2	5.7	1.5	.97	.056	17.30	1.30	0	84	61	80	5	2.15	1.03
308	¾	0.7	5.3	6.2	1.5	1.01	.061	16.05	1.40	0	84	61	100	5	2.15	1.07
309	¾	5.5	9.5	15.0	3.5	1.54	.081	17.30	2.30	0	84	65	165	5	2.15	1.63

CARBURETOR NO. 7.

[July 25, 1916; average barometer, 30.05 inches; gasoline, S. G., equals 0.683.]

Run No.	Size, inch.	Left, inches.	Right, inches.	Height, inches, water.	Pressure at Venturi inlet, inches water.	Pounds air per minute.	Pounds gas per minute.	Ratio.	Pressure drop across carburetor, inches mercury.	Pressure in box.	Inlet to carburetor.	Outlet from carburetor.	Engine revolutions per minute.	Throttle opening No.	Level in float chamber, inches.	Total pounds mixture per minute.
310	1	6.9	7.6	14.5	2.4	6.06	0.472	12.85	7.8	0	82	48	700	1	......	6.53
311	1	7.8	8.8	16.6	2.7	6.40	.508	12.60	2.0	0	82	50	850	1	......	6.91
312	1	10.0	11.4	21.4	2.3	7.23	.583	12.40	2.8	0	82	50	1,000	1	......	7.81
313	1	10.4	11.7	22.1	3.5	7.38	.580	12.75	2.8	0	82	50	1,200	1	......	7.96
314	1	10.5	11.8	22.3	3.5	7.40	.580	12.75	2.7	0	82	49	1,300	1	......	7.98
315	¾	13.0	13.2	26.2	5.4	1.98	.192	10.30	.2	0	82	50	200	1	......	2.17
316	¾	6.4	3.8	10.2	.3.0	2.00	.224	12.90	.5	0	82	50	300	1	......	3.12
317	¾	11.2	8.7	19.9	4.2	3.95	.307	12.90	1.0	0	82	50	400	1	......	4.26
318	¾	17.2	15.0	32.2	6.0	4.90	.372	13.20	1.4	0	82	48	550	1	......	5.27
319	1	7.0	7.8	14.8	2.5	6.08	.448	13.60	1.8	0	82	49	700	1	......	6.53
320	¾	5.0	2.5	7.5	2.5	2.50	.218	11.50	.2	0	82	50	250	1	......	2.72
321	¾	2.7	4.1	6.8	2.0	1.06	.096	11.10	10.7	0	82	65	220	2	......	1.16
322	¾	2.7	4.1	6.8	2.0	1.06	.099	10.70	13.5	0	82	51	300	2	......	1.16
323	¾	6.9	7.6	19.5	3.6	1.50	.171	8.50	5.1	0	82	58	......	3	......	1.67
324	¾	8.0	8.6	16.6	4.0	1.63	.157	10.40	5.0	0	82	56	220	3	......	1.79
325	¾	11.0	11.2	22.2	4.9	1.85	.153	12.10	7.2	0	82	56	300	3	......	2.00
326	¾	12.0	12.3	24.3	5.3	1.92	.138	12.20	10.8	0	82	56	400	3	......	2.08

TABLE II-VIII.—*Log of carburetor tests, Columbia University, June to August, 1916*—Continued.

CARBURETOR NO. 7—Continued.

[July 26, 1916; average barometer, 29.97 inches; gasoline, S. G., equals 0.683.]

Run No.	Venturi meter. Size, inch.	Venturi meter. Left, inches.	Venturi meter. Right, inches.	Venturi meter. Height, inches water.	Pressure at Venturi inlet, inches water.	Pounds air per minute.	Pounds gas per minute.	Ratio.	Pressure drop across carburetor, inches mercury.	Pressure in box.	Temperature, °F. Inlet to carburetor.	Temperature, °F. Outlet from carburetor.	Engine revolutions per minute.	Throttle opening No.	Level in float chamber, inches.	Total pounds mixture per minute.
327	¾	8.6	8.0	16.6	4.2	1.62	0.175	9.06	13.0	0	....	49	500	3	......	1.80
328	¾	10.3	10.6	20.9	4.5	1.80	.199	9.10	2.6	0	81	54	200	4	......	2.00
329	¾	16.3	16.0	32.3	6.5	2.20	.209	10.52	3.4	0	81	54	270	4	......	2.4
330	¾	5.9	3.2	9.1	3.0	2.75	.215	12.80	4.8	0	81	56	360	4	......	2.9
331	¾	7.7	5.1	12.8	2.8	3.23	.234	12.12	7.5	0	82	57	420	4	......	3.48
332	¾	8.4	5.7	14.1	3.0	3.40	.239	14.30	9.9	0	83	56	820	4	......	3.64
333	¾	7.0	4.5	11.5	2.5	3.07	.219	14.02	12.4	0	83	56	820	4	......	3.29
334	¾	7.0	4.5	11.5	2.5	3.07	.214	14.35	9.2	0	83	57	1,000	4	......	3.28
335	¾	4.4	1.9	6.3	1.5	2.30	.198	11.62	1.3	0	84	57	230	5	......	2.50
336	¾	7.7	5.1	12.8	2.8	3.22	.243	13.25	2.7	0	85	57	390	5	......	3.46
337	¾	13.1	10.5	23.6	4.6	4.28	.297	14.43	4.8	0	85	58	550	5	......	4.58
338	¾	15.8	13.5	29.3	5.6	4.77	.332	14.40	6.7	0	85	58	700	5	......	5.10
339	¾	16.1	13.8	30.0	6.7	4.77	.336	14.22	6.6	0	85	58	920	5	......	5.11
340	¾	16.2	13.9	30.1	5.6	4.77	.336	14.22	6.6	0	85	58	1,000	5	......	5.11

CARBURETOR NO. 8.

[Gasoline, S. G., 0.683.]

Run No.	Venturi meter. Size, inch.	Venturi meter. Left, inches.	Venturi meter. Right, inches.	Venturi meter. Height, inches water.	Pressure at Venturi inlet, inches water.	Pounds air per minute.	Pounds gas per minute.	Ratio.	Pressure drop across carburetor, inches mercury.	Pressure in box.	Temperature, °F. Inlet to carburetor.	Temperature, °F. Outlet from carburetor.	Engine revolutions per minute.	Throttle opening No.	Level in float chamber, inches.	Total pounds mixture per minute.
341	¾	12.7	13.0	25.7	5.5	1.92	0.132	14.57	0.80	0	83	57	210	1	......	2.05
342	¾	9.6	7.0	16.6	3.2	3.63	.242	15.00	.80	0	84	55	380	1	......	3.87
343	¾	15.8	13.5	29.3	5.7	4.75	.300	15.82	.80	0	84	55	500	1	......	5.05
344	1	8.7	9.8	18.5	3.0	6.80	.404	16.80	1.10	0	84	55	700	1	......	7.20
345	1	18.1	13.7	25.8	4.1	7.97	.488	16.30	1.30	0	84	52	000	1	......	8.46
346	1	13.1	14.8	27.9	4.4	8.20	.523	15.70	.30	0	85	56	1,140	1	......	8.72
347	1	13.4	15.2	28.6	4.6	8.35	.528	15.70	1.30	0	86	54	1,300	1	......	8.88
348	¾	9.3	10.0	19.3	4.5	1.75	.112	15.60	3.50	0	85	63	225	2	......	1.86
349	¾	15.1	14.9	30.0	6.2	2.12	.144	14.72	5.60	0	85	61	320	2	......	2.26
350	¾	24.3	22.0	46.2	8.7	2.53	.181	14.00	9.00	0	85	58	450	2	......	2.71
351	¾	6.0	3.4	0.4	2.0	2.80	.190	14.71	10.40	0	84	57	580	2	......	2.99
352	¾	6.2	3.7	10.0	2.3	2.88	.194	14.87	11.40	0	84	57	700	2	......	3.07
353	¾	6.3	3.7	9.9	2.2	2.88	.200	14.40	10.90	0	85	57	880	7	......	3.08
354	¾	6.4	3.8	10.2	2.2	2.90	.197	14.73	10.90	0	85	57	880	2	......	3.10
355	¾	15.1	14.8	29.9	6.3	2.12	.147	14.42	.65	0	85	60	240	3	......	2.27
356	¾	11.7	9.1	20.8	4.0	4.07	.206	15.30	.75	0	85	60	440	3	......	4.34
357	¾	19.5	18.0	37.0	7.2	5.25	.338	15.50	1.00	0	85	52	580	3	......	5.59
358	1	9.0	10.0	19.0	3.1	6.78	.432	15.70	1.30	0	85	51	750	3	......	7.21
359	1	11.6	13.0	24.6	4.0	7.70	.482	16.00	1.45	0	86	51	900	3	......	8.18
360	1	12.2	13.8	26.0	4.2	7.85	.443	15.84	1.50	0	87	53	1,100	3	......	8.35
361	1	12.8	14.5	27.3	4.5	7.95	.506	19.70	1.50	0	87	52	....	3	......	8.46

[July 27, 1916; average barometer, 29.86 inches; gasoline, S. G., 0.683.]

Run No.	Venturi meter. Size, inch.	Venturi meter. Left, inches.	Venturi meter. Right, inches.	Venturi meter. Height, inches water.	Pressure at Venturi inlet, inches water.	Pounds air per minute.	Pounds gas per minute.	Ratio.	Pressure drop across carburetor, inches mercury.	Pressure in box.	Temperature, °F. Inlet to carburetor.	Temperature, °F. Outlet from carburetor.	Engine revolutions per minute.	Throttle opening No.	Level in float chamber, inches.	Total pounds mixture per minute.
362	1	9.0	10.2	19.2	3.2	6.90	0.415	16.60	1.0	0	81	55	740	1	......	7.32
363	1	11.5	12.7	24.2	3.9	7.70	.464	16.62	1.2	0	81	52	880	1	......	8.16
364	¾	13.0	12.8	25.8	5.3	1.98	.135	14.65	1.2	0	81	60	213	4	......	2.12
365	¾	8.0	5.3	13.3	......	3.32	.236	14.10	2.0	0	81	60	380	4	......	3.56
366	¾	14.4	12.0	26.4	5.0	4.50	.322	14.00	3.5	0	81	59	840	4	......	4.82
367	¾	21.5	19.8	41.3	7.6	5.46	.375	14.84	4.8	0	81	59	750	4	......	5.83
568	1	6.4	7.1	13.5	2.2	5.83	.371	15.72	5.7	0	83	60	1,031	4	......	6.20
369	1	6.5	7.2	13.7	2.2	5.90	.374	15.75	5.9	0	83	60	940	4	......	5.07
370	¾	3.6	4.8	8.3	4.0	1.16	.109	10.65	3.0	0	82	65	200	5	......	1.27
371	¾	16.8	16.2	33.0	7.7	2.20	.163	13.50	6.0	0	82	65	350	5	......	2.36
372	¾	16.5	3.7	10.2	2.5	2.89	.200	14.43	8.9	0	82	59	530	5	......	3.09
373	¾	7.0	4.3	11.3	2.5	3.04	.208	14.61	11.2	0	82	58	730	5	......	3.25
374	¾	6.6	4.0	10.6	2.2	2.95	.208	14.80	10.2	0	82	58	930	5	......	3.16

TABLE II-VIII.—*Log of carburetor tests, Columbia University, June to August, 1916*—Continued.

CARBURETOR NO. 5.

[July 28, 1916; average barometer, 30.25 inches; gasoline, S. G., 0.683.]

Run No.	Venturi meter. Size, inch.	Left, inches.	Right, inches.	Height, inches water.	Pressure at Venturi inlet, inches water.	Pounds air per minute.	Pounds gas per minute.	Ratio.	Pressure drop across carburetor, inches mercury.	Pressure in box.	Temperature, °F. Inlet to carburetor.	Outlet from carburetor.	Engine revolutions per minute.	Throttle opening No.	Level in float chamber, inches.	Total pounds mixture per minute.
375	¾	15.9	15.5	31.4	6.4	2.16	0.124	17.4	1.00	0	80	42	230	1	2.4	2.28
376	¾	9.2	6.3	15.5	2.7	3.55	.200	17.8	1.00	0	80	42	370	1	2.4	3.75
377	¾	17.6	15.5	33.1	5.8	4.06	.304	16.3	1.00	0	80	42	500	1	2.4	5.26
378	1	8.5	9.3	17.8	2.9	6.70	.397	15.86	1.20	0	81	38	700	1	2.3	7.10
379	1	12.0	13.4	25.4	3.9	7.80	.487	16.00	1.50	0	81	38	860	1	2.3	8.29
380	1	13.2	14.7	27.9	4.7	8.17	.562	14.55	1.60	0	82	38	1,040	1	2.3	8.73
381	1	13.3	15.0	28.3	4.7	8.27	.543	15.20	1.55	0	82	38	1,130	1	2.3	8.81
382	1	13.0	14.6	27.6	4.5	8.15	.543	14.80	1.60	0	83	38	1,330	1	2.3	8.69
383	1	7.8	8.6	16.4	2.6	6.50	.380	16.85	1.20	0	83	38	700	1	2.3	6.88
384	1	12.8	14.3	27.1	4.3	8.13	.558	14.56	1.60	0	83	38	1,040	1	2.3	8.69
385	¾	16.4	14.1	30.5	5.7	4.80	.287	10.75	1.00	0	82	38	500	1	2.3	5.09
386	¾	6.0	6.0	12.0	4.0	.289	.035	8.23	11.7	0	81	50	175	2	2.3	.323
387	¾	7.0	6.8	13.8	4.5	.308	.033	9.64	13.9	0	80	50	235	2	2.3	.341
388	¾	4.8	4.4	9.2	3.3	.255	.043	5.94	13.9	0	80	50	285	2	2.3	.298
389	¾	3.3	2.5	5.3	2.1	.204	.040	5.10	14.8	0	80	52	390	2	2.3	.244
390	¾	4.9	3.2	7.2	2.6	.227	.040	5.56	14.3	0	80	49	245	2	2.3	.267
391	¾	5.0	4.5	9.5	3.3	.260	.047	5.53	9.7	0	80	49	120	2	2.3	.307
392	¾	4.0	4.0	8.0	3.3	.238	.046	5.17	13.2	0	80	49	180	2	2.3	.284
393	¾	10.5	7.8	18.3	3.7	4.61	.232	19.90	1.0	0	82	40	400	3	2.3	4.840
394	¾	12.5	15.6	28.1	5.7	2.07	.134	15.55	.9	0	81	45	225	3	2.3	2.200
395	¾	22.7	21.2	43.9	8.2	5.60	.372	16.10	1.15	0	81	42	600	3	2.3	5.970
396	1	8.2	9.0	17.2	2.8	6.57	.408	16.11	1.35	0	82	42	700	3	2.3	6.98
397	1	10.3	11.4	21.7	3.4	7.26	.462	15.70	1.50	0	83	44	820	3	2.3	7.71
398	1	11.6	13.0	24.6	3.8	7.68	.498	15.42	1.60	0	83	44	900	3	2.3	8.18
399	1	12.2	13.6	25.8	4.2	7.90	.514	15.40	1.60	0	84	45	1,000	3	2.3	8.41
400	1	12.5	13.9	26.4	4.3	8.00	.528	15.15	1.70	0	84	46	1,100	3	2.3	8.53
401	1	12.8	14.3	27.1	4.5	8.00	.535	14.95	1.70	0	84	46	1,240	3	2.3	8.54
402	1	12.7	14.2	26.9	4.5	8.00	.545	14.66	1.60	0	84	44	1,300	3	2.3	8.55
403	¾	9.5	6.9	16.4	3.3	3.62	.207	17.50	1.00	0	84	44	380	3	2.3	3.83
404	¾	10.2	7.6	17.8	3.8	3.75	.228	16.47	1.00	0	83	43	400	3	2.3	3.98
405	¾	10.0	11.0	25.0	4.8	4.37	.262	16.70	1.00	0	84	40	480	3	2.3	4.63
406	¾	22.1	20.5	42.6	7.7	5.53	.332	16.67	1.20	0	84	40	610	3	2.3	5.86
407	¾	8.6	12.0	20.6	4.6	1.37	.112	12.23	1.00	0	84	50	200	4	2.3	1.48
408	¾	9.3	6.6	15.9	3.3	3.56	.200	17.80	1.30	0	84	48	380	4	2.3	3.76
409	¾	16.5	14.2	30.7	5.7	4.82	.278	17.35	1.80	0	84	47	520	4	2.3	5.10
410	¾	21.3	19.2	40.5	7.7	5.40	.307	17.60	2.15	0	84	46	620	4	2.3	5.71
411	1	7.0	7.7	14.7	2.3	6.08	.357	17.06	2.50	0	84	46	700	4	2.3	6.44
412	1	9.2	10.2	19.4	3.3	6.95	.430	16.15	2.95	0	84	46	860	4	2.3	7.18
413	1	9.7	10.9	20.6	3.3	7.10	.450	15.78	3.00	0	84	50	960	4	2.3	7.38
414	1	9.7	10.8	20.5	3.3	7.10	.433	16.40	3.10	0	84	50	1,100	4	2.3	7.56
415	¾	10.2	13.7	23.7	5.6	1.92	.123	15.60	1.00	0	84	52	205	4	2.3	2.04
416	¾	6.2	3.4	9.6	2.0	2.80	.169	16.57	1.10	0	84	52	300	4	2.3	2.97
417	¾	9.1	6.5	15.6	3.4	3.58	.206	17.40	1.40	0	84	51	380	4	2.3	3.78
418	¾	6.4	10.0	16.0	3.8	1.58	.097	16.28	2.60	0	84	60	210	5	2.3	1.68
419	¾	4.0	8.3	12.3	2.9	1.40	.082	17.05	2.00	0	84	54	165	5	2.3	1.48
420	¾	14.5	17.5	32.0	6.4	2.18	.141	15.48	4.60	0	84	51	305	5	2.3	2.32
421	¾	6.5	3.8	10.3	3.3	2.90	.159	18.25	6.90	0	84	52	450	5	2.3	3.06
422	¾	6.8	4.1	10.9	2.4	2.98	.163	18.30	9.50	0	84	54	560	5	2.3	3.14
423	¾	7.2	4.4	11.6	2.4	3.05	.170	17.95	10.40	0	84	58	680	5	2.3	3.22
424	¾	7.0	4.4	11.4	2.5	3.05	.181	16.85	10.60	0	84	56	850	5	2.3	3.23
425	¾	20.0	21.7	41.7	8.3	2.43	.146	16.70	6.30	0	84	56	380	5	2.3	2.58
426	¾	7.1	4.3	11.4	2.5	3.05	.173	17.65	10.50	0	84	56	1,000	5	2.3	3.22

CARBURETOR NO. 4.

[July 31, 1916; average barometer, 29.85 inches; gasoline, S. G., 0.683.]

427	¾	15.8	18.2	34.0	7.0	2.24	0.154	14.55	0	0	86	54	230	1	......	2.39
428	¾	11.7	8.7	30.4	4.1	4.05	.244	16.60	.4	0	86	56	400	1	......	4.29
429	¾	22.5	20.2	42.7	8.4	5.60	.334	16.75	1.0	0	86	52	580	1	......	5.93
430	1	10.3	11.4	21.7	3.3	7.28	.461	15.78	2.0	0	88	55	840	1	......	7.74
431	¾	11.0	8.3	19.3	3.7	3.97	.244	16.30	.4	0	88	55	400	1	......	4.21
432	1	11.4	12.4	23.3	3.7	7.00	.477	15.90	2.2	0	88	58	940	1	......	8.08
433	1	11.7	12.8	24.5	3.8	7.70	.488	15.75	2.5	0	88	56	1,070	1	......	8.19
434	1	11.7	12.9	24.6	3.8	7.70	.497	15.50	2.5	0	88	56	1,240	1	......	8.20
435	1	7.6	8.3	15.9	2.7	6.31	.383	16.50	1.2	0	88	56	680	1	......	6.69
436	¾	8.0	5.1	13.1	2.6	3.27	.215	15.20	.3	0	88	56	310	1	......	3.49
437	¾	5.0	9.0	14.0	3.3	1.48	.114	13.00	3.8	0	88	60	195	2	......	1.59
438	¾	8.1	11.7	19.8	4.5	1.75	.128	13.67	6.6	0	88	60	295	2	......	1.88

TABLE II-VIII.—*Log of carburetor tests, Columbia University, June to August, 1916*—Continued.

CARBURETOR No. 4—Continued.

Run No.	Venturi meter.				Pressure at Venturi inlet, inches water.	Pounds air per minute.	Pounds gas per minute.	Ratio.	Pressure drop across carburetor, inches mercury.	Pressure in box.	Temperature, °F.		Engine revolutions per minute.	Throttle opening No.	Level in float chamber, inches.	Total pounds mixture per minute.
	Size, inch.	Left, inches.	Right, inches.	Height, inches water.							Inlet to carburetor.	Outlet from carburetor.				
439	½	11.8	15.0	26.8	5.7	2.02	0.144	14.03	10.4	0	88	62	420	2	......	2.16
440	½	11.9	15.0	26.9	5.7	2.03	.142	14.27	12.3	0	88	59	530	2	......	2.17
441	½	11.7	14.9	26.6	5.7	2.01	.143	14.05	12.3	0	89	58	700	2	......	2.15
442	½	12.0	14.8	26.8	5.8	2.02	.134	15.10	11.9	0	89	58	880	2	......	2.15
443	½	12.0	15.0	27.0	5.7	2.03	.131	15.50	11.3	0	89	59	990	2	......	2.16
444	½	12.0	15.0	27.0	5.8	2.03	.138	14.70	10.6	0	89	59	1,100	2	......	2.17
445	½	5.0	2.0	7.0	1.6	2.42	.161	15.02	0	0	88	54	240	3	......	2.58
446	½	7.8	5.0	12.8	2.7	3.16	.208	15.20	.4	0	88	54	330	3	......	3.37
447	½	11.0	8.2	19.2	3.7	3.88	.245	15.85	.6	0	88	52	400	3	......	4.13
448	½	17.8	15.6	33.4	6.3	5.00	.311	16.10	1.0	0	89	55	520	3	......	5.31
449	1	6.8	7.3	14.1	2.2	5.98	.366	16.35	1.5	0	89	55	650	3	......	6.35
450	1	8.6	9.3	17.9	2.9	6.68	.413	16.20	2.0	0	89	57	760	3	......	1.09
451	1	10.3	11.3	21.6	3.7	7.26	.458	15.87	2.5	0	89	58	900	3	......	7.72
452	1	11.0	12.0	23.0	3.9	7.50	.472	15.90	2.6	0	89	57	1,090	3	......	7.97
453	1	11.0	12.0	23.0	4.0	7.50	.480	15.61	2.7	0	89	57	1,250	3	......	7.98
454	½	4.6	1.6	6.2	1.6	2.28	.147	15.50	.4	0	89	58	220	4	......	2.43
455	½	7.3	4.5	11.8	2.6	3.10	.194	16.00	.8	0	89	57	325	4	......	3.29
456	½	10.8	8.0	18.8	2.7	3.86	.240	16.07	1.2	0	90	57	410	4	......	4.10
457	½	17.5	15.0	32.5	6.2	4.97	.300	16.51	2.1	0	90	57	540	4	......	5.27
458	1	7.3	7.9	15.2	2.5	6.20	.379	16.35	3.4	0	91	61	760	4	......	6.58
459	1	7.0	7.6	14.6	2.3	6.10	.381	16.00	3.4	0	91	61	760	4	......	6.48
460	1	8.0	8.7	16.7	2.8	6.50	.389	16.62	3.9	0	90	60	910	4	......	6.89
461	1	8.5	9.2	17.7	3.1	6.68	.407	16.41	4.2	0	90	59	1,020	4	......	7.09
462	1	8.3	9.0	17.3	3.0	6.97	.408	16.02	4.3	0	90	61	1,120	4	......	6.91
463	½	20.0	17.5	37.5	7.2	5.26	.328	16.00	2.5	0	91	61	640	4	......	5.39
464	½	11.3	14.5	25.8	5.4	1.97	.141	13.97	1.0	0	92	66	230	5	......	2.11
465	½	6.0	3.1	9.1	2.0	2.74	.176	15.56	2.0	0	92	62	310	5	......	2.92
466	½	7.4	4.7	12.1	2.5	3.12	.197	15.82	2.5	0	92	62	390	5	......	3.06
467	½	11.5	9.0	20.0	4.3	4.01	.249	16.15	4.4	0	92	63	500	5	......	4.27
468	½	14.0	11.2	25.2	5.0	4.40	.269	16.39	6.6	0	92	63	610	5	......	4.68
469	½	15.2	12.6	27.8	5.4	4.60	.275	16.72	6.1	0	92	63	720	5	......	4.80
470	½	16.4	14.1	30.5	5.8	4.80	.295	16.25	7.5	0	92	63	850	5	......	5.17
471	½	15.7	13.3	29.0	5.6	4.69	.283	16.52	6.0	0	92	63	1,000	5	......	4.96
472	½	15.6	13.0	28.6	5.9	4.67	.290	16.20	6.5	0	92	65	1,110	5	......	4.92

CARBURETOR NO. 9.

[Aug. 1, 1916; average barometer, 29.96 inches; gasoline, S. G., 0.683.]

473	½	0.6	5.0	5.6	1.0	0.960	0.079	12.15	10.7	0	87	48	220	2	......	1.04
474	½	.5	4.8	5.3	1.5	.940	.079	11.90	10.15	0	86	46	320	2	......	1.01
475	½	.4	4.7	5.1	1.4	.920	.080	11.50	15.20	0	86	46	400	2	......	1.00
476	½	18.7	19.8	38.5	11.7	.493	.065	7.60	9.0	0	86	48	170	2	......	.66
477	½	18.5	20.0	38.5	11.5	.493	.061	8.08	7.4	0	86	50	140	2	......	.65
478	½	8.9	12.2	21.1	4.6	1.85	.172	10.76	1.3	0	87	44	210	1	......	2.02
479	½	7.5	4.5	12.0	1.6	3.11	.240	12.95	1.7	0	88	45	340	1	......	3.35
480	½	12.8	10.0	22.8	4.7	4.21	.314	13.40	2.1	0	90	45	450	1	......	4.52
481	½	18.6	16.3	34.8	6.6	5.09	.354	14.38	2.2	0	90	45	560	1	......	5.44
482	1	6.8	7.2	14.0	2.5	5.96	.388	15.35	2.6	0	91	48	680	1	......	6.34
483	1	9.1	9.9	19.0	3.3	6.88	.430	16.40	2.9	0	92	50	840	1	......	7.31
484	½	6.9	10.3	16.9	4.0	1.63	.174	9.38	1.2	0	92	48	180	1	......	1.80
485	1	9.5	10.2	19.7	3.3	7.00	.450	15.55	3.0	0	94	50	960	1	......	7.45
486	1	9.9	10.7	20.6	3.4	7.10	.445	15.95	3.1	0	94	53	1,070	1	......	7.55
487	1	11.0	11.7	22.7	3.6	7.50	.455	16.65	3.3	0	96	56	1,240	1	......	7.96
488	½	11.1	14.0	25.1	5.7	1.95	.186	10.50	1.5	0	92	51	220	3	......	2.14
489	½	7.6	4.6	12.2	2.6	3.13	.261	12.00	1.7	0	92	46	350	3	......	3.39
490	½	13.2	10.5	23.7	4.6	4.20	.342	12.03	2.2	0	93	47	480	3	......	4.63
491	½	18.8	16.9	35.2	6.7	5.10	.388	13.15	2.6	0	94	48	600	3	......	5.49
492	1	7.3	7.8	15.1	2.6	6.17	.430	14.35	2.9	0	94	48	720	3	......	6.60
493	½	5.6	9.2	14.8	3.4	1.53	.179	8.60	1.3	0	94	51	175	3	......	1.71
494	1	9.0	9.7	18.7	3.0	6.80	.422	16.11	2.9	0	94	51	850	3	......	7.22
495	1	10.0	10.8	20.8	3.6	1.18	.453	15.92	3.2	0	97	50	980	3	......	7.63
496	1	10.0	10.8	20.8	3.4	7.18	.462	15.55	3.2	0	98	51	1,090	3	......	7.64
497	1	10.2	11.1	21.1	3.4	7.20	.463	15.56	3.4	0	98	52	1,260	3	......	7.66
498	½	10.0	13.0	23.0	5.1	1.87	.181	10.33	1.6	0	96	54	205	4	......	2.05
499	½	24.5	25.2	49.7	9.6	2.62	.240	10.91	2.1	0	94	47	310	4	......	2.86
500	½	12.5	9.8	22.3	4.3	4.18	.330	12.67	2.9	0	95	50	490	4	......	4.51
501	½	17.8	15.3	33.1	6.3	5.00	.372	13.43	3.5	0	96	50	600	4	......	5.37
502	1	6.0	6.4	12.4	2.2	5.60	.396	14.15	3.8	0	97	49	700	4	......	6.00
503	1	7.3	7.8	15.1	2.5	6.20	.400	15.50	4.6	0	98	52	880	4	......	6.60
504	1	7.3	7.9	15.2	2.5	6.21	.430	14.43	4.4	0	98	58	1,000	4	......	6.64
505	1	7.6	8.0	15.6	2.6	6.23	.430	14.50	4.6	0	98	54	1,130	4	......	6.66

TABLE II-VIII.—*Log of carburetor tests, Columbia University, June to August, 1916*—Continued.

CARBURETOR NO. 9—Continued.

[Aug. 2, 1916; barometer, 30.17 inches; gasoline, S. G., 0.683.]

Run No.	Venturi meter.				Pressure at Venturi inlet, inches water.	Pounds air per minute.	Pounds gas per minute.	Ratio.	Pressure drop across carburetor, inches mercury.	Pressure in box.	Temperature, °F.		Engine revolutions per minute.	Throttle opening No.	Level in float chamber, inches.	Total pounds mixture per minute.
	Size, inch.	Left, inches.	Right, inches.	Height, inches water.							Inlet to carburetor.	Outlet from carburetor.				
506	[illegible]	5.7	9.2	14.9	3.4	1.55	0.175	8.85	2.1	0	80	46	190	5	......	1.73
507	[illegible]	11.5	14.0	25.5	5.7	1.97	.189	10.42	5.8	0	80	45	300	5	......	2.16
508	[illegible]	1.8	5.7	7.5	1.9	1.10	.125	8.80	1.3	0	81	44	110	5	......	1.23
509	[illegible]	10.6	13.4	24.0	5.2	1.92	.131	10.60	3.5	0	82	45	240	5	......	2.10
510	[illegible]	6.0	9.5	15.5	3.7	1.57	.139	11.30	9.5	0	82	45	350	5	......	1.71
511	[illegible]	7.0	10.3	17.3	4.2	1.66	.185	2.00	9.5	0	82	46	350	5	......	1.85

By means of a stop watch the time required to consume a definite weight of fuel was determined, and the run was continued until three consecutive readings showed the flow to be steady and the rate of flow constant.

In general each carburetor was tested for five different throttle positions, including idling and full throttle, and at a sufficient number of engine speeds at each throttle position. Whenever the readings showed that the *critical pressure* had been reached, so that an increase in engine speed would not produce an increase of flow, the throttle was changed to its next position. In each case the lowest speed was the minimum speed at which the dynamometer could be operated.

All carburetors were tested with standard gasoline of 62.5° Baumé, and a number of them also with gasoline of 75° Baumé. The former was bought from the Standard Oil Co., and the latter was obtained from the American Oil Works, Titusville, Pa.

The following carburetors, all modern compensating forms, were very kindly loaned by their makers for the purpose of these tests when requested through the National Automobile Chamber of Commerce, but the trade names are suppressed for obvious reasons.

Mark No.	Diameter of outlet.	New class.	Mark No.	Diameter of outlet.	New class.
	Inches.			*Inches.*	
1...........................	1 11/16	13.5	6...........................	[illegible]	14.1
2...........................	(?)	13.4	7...........................	[illegible]	8.2
3...........................	[illegible]	12.5	8...........................	[illegible]	12.7
4...........................	[illegible]	6.5	9...........................	1 11/16	10.9
5...........................	[illegible]	12.5	10...........................	[illegible]	9.2

It had been the intention to test two other makes of carburetors, but, although promised by the makers, delivery was not made.

It is most important that the results of these tests be not misinterpreted, and it must be emphasized again that the tests should not be considered in any way as competitive. In the first place, only one feature of each carburetor was brought out, namely, the accuracy of the proportioning of the mixture at different flow rates, and this does not throw any light on the intimacy or homogeneity of the

mixture, its density, or its degree of dryness. But even with respect to proportions the results should be quoted or considered only in so far as they tend to reveal the characteristics of the variations from constancy with reference to flow rate for the general sort of carburetor under study. No attempt was made to improve the performance of each carburetor after the object stated had been attained. For instance, where a carburetor has separate adjustments for each throttle position, as in one well-known type, the adjustments were not continued after the plotted curves of the results had shown plainly what might and what might not be effected by further adjustment. In the same way, where the auxiliary air supply is regulated by spring-loaded valves, no attempt was made to find the effect of different springs or spring tensions, since it is well known what effect a lighter or heavier spring or a change in the initial tension will produce.

Furthermore, since all carburetors showed an appreciable variation in the proportions of the mixture under widely varying conditions it is not important that the whole proportionality range of one is lower than the whole range of another over the same range of flow rates. Obviously the flow rate range is a matter of option in use.

Where a carburetor has an independent arrangement for idling controlled by the throttle position or the vacuum above the throttle, so that it really consists of two distinct carburetors with separate jets, the idling mixture was not very carefully adjusted, since this is a manual operation and its result quite independent of the automatic compensations over the working ranges of flow rates. Whenever an individual result was obtained that seemed inconsistent the run was repeated, and errors in calculations or readings were thus quickly found out and eliminated during the progress of the test. Under these conditions and considering the methods and apparatus used the final results should be correct within 1 per cent.

The proportionality results for each carburetor have beeen plotted in three different ways:

(A) Ratio of air to gasoline by weight as ordinates, plotted against total weight of mixture as abscissæ, designated by the letter "A," on the curve sheets.

(B) Same ordinates as in the previous case, plotted against the total pressure drop across carburetor as abscissæ, designated by the letter "B," on the curve sheets.

(C) Weight of gasoline as ordinates, plotted against weight of air as abscissæ, designated by the letter "C," on the curve sheets.

Where two kinds of gasoline were used sheets marked A_1 and A_2 and C_1 and C_2 will be found, the subscript 1 denoting the heavier fuel and 2 the lighter. B was plotted only for the heavier fuel, since it does not help the understanding very much; so B only will be found.

The throttle positions are marked by numbers. (See any A or B sheet.) These numbers were assigned for convenience only and give no indication as to the degree of throttle opening. By means of these numbers and the corresponding symbols the points of a group can be kept together and recognized; also it will be easy to find the corresponding reading on the log sheets where the same numbers are used.

On the C sheets no numbers are used, and the points of any one group have simply been given a characteristic mark, which does not necessarily agree with the symbols of the same group on the A and B sheets. Since the C curve has only been used to give an idea of the general nature of the mean curve of all results, this discrepancy, which was discovered too late, does not matter.

It should also be noted that where two tests were run on one carburetor no attempt was made to test it with exactly the same throttle position in both cases. Since the tests had to be run on different days and the carburetor was removed from the box between the two tests, and because in some throttle positions even the very slightest motion of the throttle will affect the flow considerably, the same throttle positions could not have been reproduced without a very accurate system of marking, which would have required too much time.

The individual points had at first been combined into smooth curves, representing mean values, but this method was abandoned, since it appeared, first, that it in no way helped the understanding, and, second, because in some cases results were so erratic that they could not fairly be represented by smooth curves. Accordingly the test points are joined by straight lines on the curve sheets.

On inspecting the curves it will be oberved that the relation A and B make the irregularities appear far more conspicuous than the relation C. The latter is the one most commonly used in reports on carburetor tests, which is rather peculiar, since it does not give to the eye a striking picture of one of the main characteristics of the carburetor, namely, proportionality, and tends to obscure its variations.

Constancy of proportion of gasoline to air will in each case be represented by straight lines, these being in the relations A and B horizontal lines, and in C inclined and passing through the origin. The relation C has the advantage that its curve furnishes the best means of quickly deducing the equation representing flow of air, which is important when the performance of a carburetor is to be investigated in the light of the rational or empirical flow laws. It, however, does not convey an accurate idea of the fluctuation in the mixture proportions, since naturally a very much smaller scale has to be adopted for the gasoline than for the air. In this report the gasoline scale on sheets C is only one-tenth that of the air scale. It must also be remarked that in all the reports of carburetor tests that have been found in the literature of the subject present curves of the relation of C only, and individual points are generally suppressed in favor of a smooth curve. In the light of these new test results this older practice seems improper, because it suppresses the very facts that should form the basis or object of the test.

Each carburetor in turn is described briefly and its test results reported in curve form without elaborate discussion. A photograph of the instrument and a sectional or phantom view of its construction will serve to identify the device, full description of which may be found in the trade literature by those not already familiar with it from personal observation or use.

Carburetor No. 1.—This carburetor has a fuel needle valve controlled by an automatic spring-loaded secondary air-inlet valve with a fixed primary air inlet and is therefore a representative of the new

subclass 13.5. It is illustrated in figure 6, and the results of the test are given in curve form in figures 7, 8, and 9, which represent, respectively, the relations A, B, and C. Reference to the curves A on figure 7 shows that—

(*a*) The mixture gets leaner as the flow rate increases, or that the fuel increases faster than the air.

(*b*) Neglecting the idling points where the ratio of air to fuel is about 9, the ratio varies from 10.3 to 13.1 over the working range between 2 and 9 pounds of mixture per minute approximately, which is 24 per cent on the mean ratio of 11.7.

(*c*) For a given flow rate the mixture is not the same for different tests as shown by the disposition of points on a given vertical line, but in general this variation is not very large.

(*d*) There are certain irregularities for which the only explanation that can be found is irregular mechanical action or sticking of the moving parts, the automatic valve, the fuel needle valve, or lost motion in the linkage.

Reference to the curve sheet B, figure 8, indicates that on idling the pressure drop through the carburetor, which is, of course, the vacuum in the intake manifold, varied from 11.5 to 14.5 inches of mercury, and over the working range noted above from 0.8 to 9.7 inches of mercury. Finally, reference to figure 9, the plot of relations C, giving the fuel weight with reference to air weight, shows far less clearly the variations in proportion that really exist than does figure 7, the plot of relations A, which gives the ratio of air to fuel directly as a function of mixture flow rate.

The curves could have been made to change in shape or curvature by a change of spring or spring tension, but there is no indication that a straight line would result or that the irregularities would disappear.

Observations of the level in the float chamber showed that it varied 0.55 inch over the flow range, which is large in proportion to the height of the fuel nozzle above the mean level and must account for some of the variations.

Carburetor No. 2 (*fig. 10*).—In the carburetor the fuel needle valve is throttle controlled by a link connection, and air enters partly through a fixed primary and partly through an automatic spring-loaded valved secondary inlet, so that it may be regarded as an example of the new subclass 13.4. An interesting comparison becomes possible between the results of this and those of carburetor No. 1, because the two devices are, in general, similar in all respects except for the needle-valve control, which is here throttle actuated and in the previous case moved by the automatic secondary air valve. It has already been pointed out that the throttle position is not a prime variable in flow while automatic air-valve movement may be and is so, the more nearly it controls all the air and the more nearly constant its spring tension. This being the case, more variation from constancy would be expected in this carburetor than in the last one for variation of flow rates, due to changes of engine speed with a fixed throttle. With such a fixed throttle any changes in flow rate act on proportions in just the same way as would be the case with a fixed fuel inlet associated with fixed primary and automatic secondary air inlets. If the compensation for such a combination were adequate, there would be

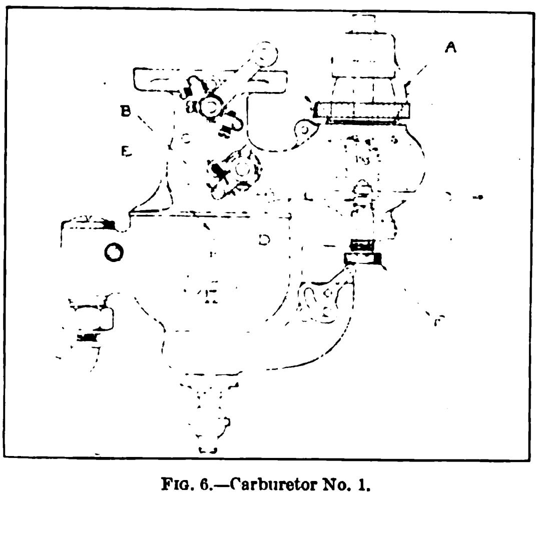


FIG. 6.—Carburetor No. 1.

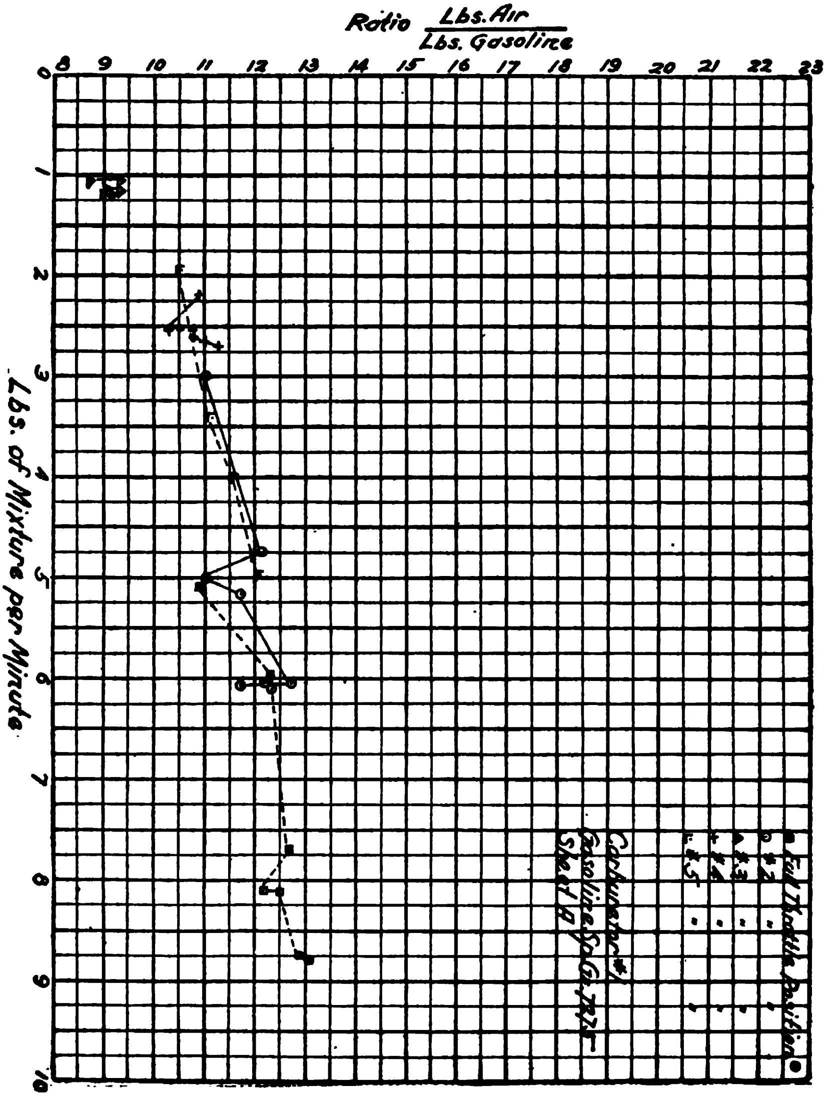

Ratio Lbs. Air / Lbs. Gasoline
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Lbs. of Mixture per Minute
0 1 2 3 4 5 6 7 8 9 10
Carburetor #1
Gasoline Sp.Gr. .7375
Sheet A

Fig. 7.

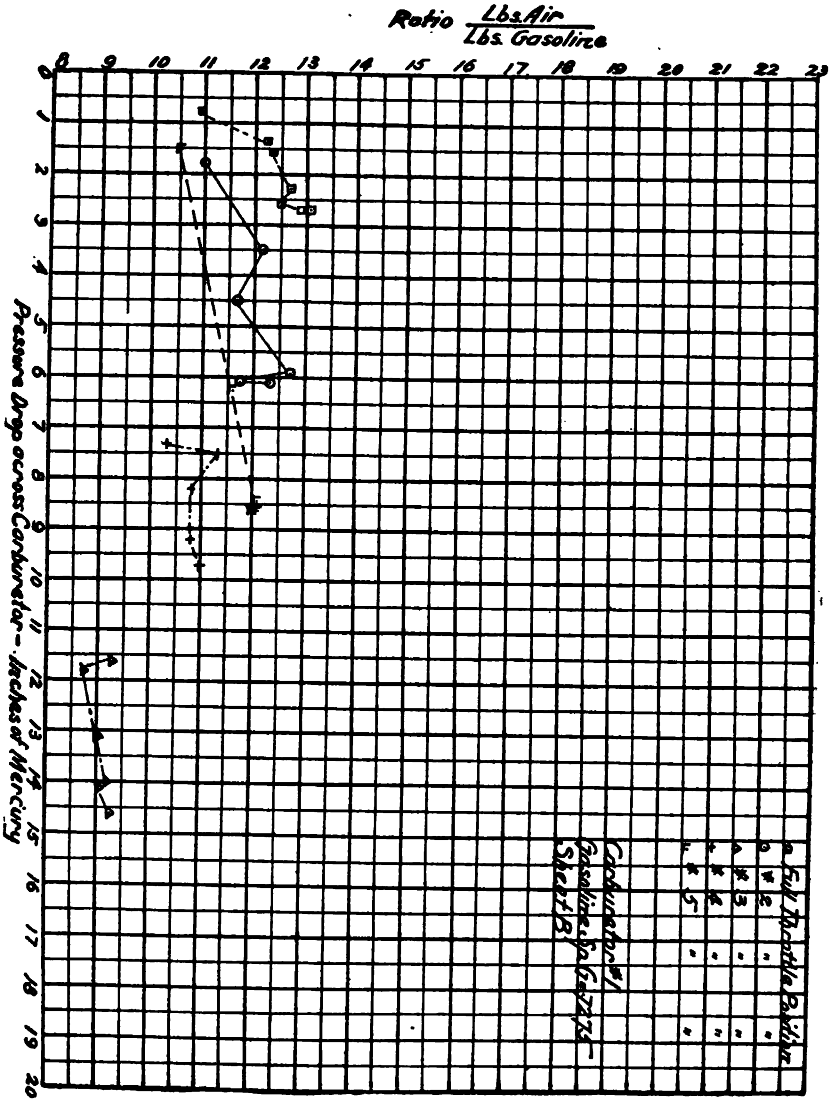

Ratio Lbs. Air / Lbs. Gasoline
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Pressure Drop across Carburetor - Inches of Mercury
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Carburetor #1
Sheet 8

Fig. 8.

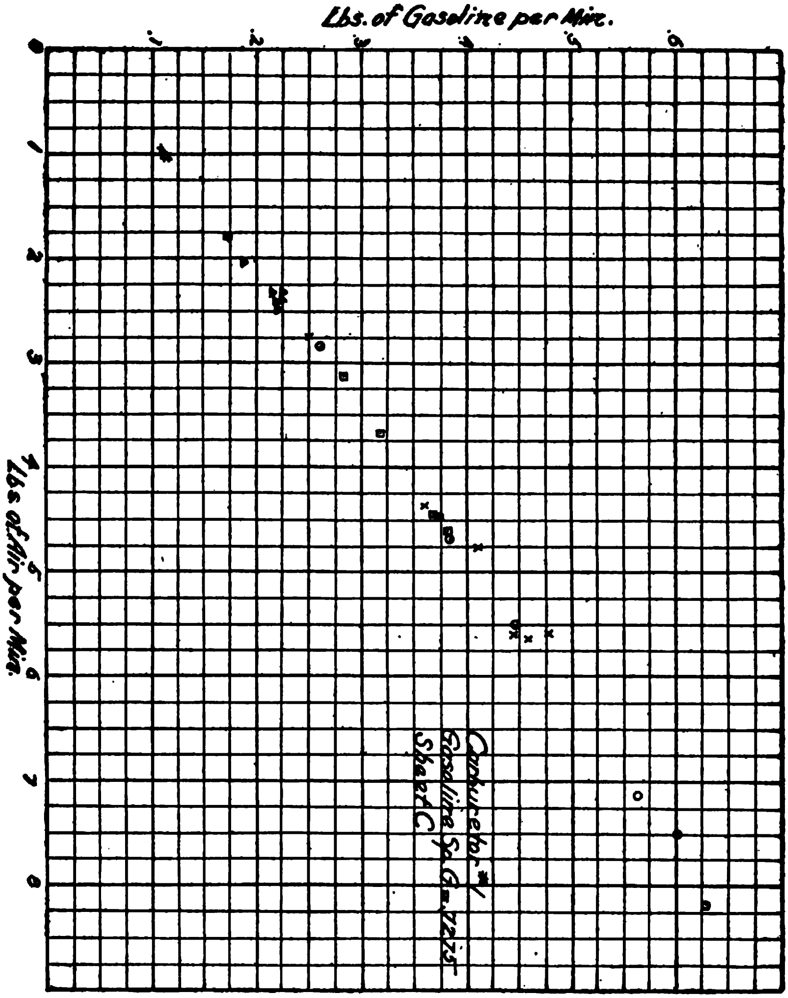

Lbs. of Gasoline per Min.
Lbs of Air per Min.
Carburetor #1
Gasoline Sp. Gr. .7275
Sheet C

Fig. 9.

no object in adding the second compensator, which is out of action when the throttle is fixed.

Reference to the curves of air to fuel ratio with respect to mixture flow rate, the A relation given in figure 11 leads to the following conclusions:

(*a*) The proportions vary widely in passing from one throttle position to another for a given flow rate along a vertical line. For example, at a mixture flow rate of 7 pounds per minute the air to fuel ratio varies from 15.4 to about 29, nearly 100 per cent in passing from No. 2 to No. 5 throttle position. While manual adjustment of the cam connection between needle and throttle may be relied upon to reduce this, there is no reason to believe that the difference can ever be reduced to zero.

(*b*) The proportions vary also over a very wide range with any fixed throttle position as the flow rate changes with engine speed as is clear from the rising trend of all the curves. For example, the ratio for throttle position No. 5, and flow rate 2.5 pounds per minute is about 14.5, which increases to 29 for a flow rate of 7 pounds per minutes with the same throttle position. This is exactly double, or 100 per cent of the lower value and 67 per cent of the mean ratio of 21.75. Hand adjustment of the automatic air-valve spring tension will, of course, tend to flatten these curves, but it is not likely that they can by this means ever be brought to horizontal lines.

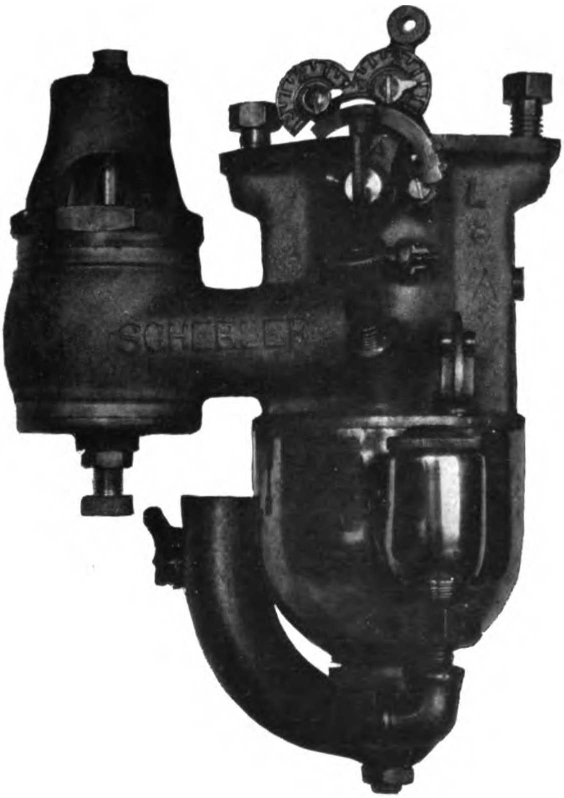
(*c*) The curves are all smooth and the irregularity noted for carburetor No. 1 is absent, which confirms the opinion that these irregularities were due to sticking or lost motion of the air valve or its curvatures. In the present case the air valve is free and the needle linkage is positively actuated by the manual movement of the throttle. Reference to the pressure drop curves (fig. 12) will give the pressure drop or header vacuum corresponding to the several flow-rate and throttle-position points or the proportions corresponding to them. As in the previous case the direct relation of fuel to air weights of figure 13 clearly fails to bring out the departures from constancy of proportion as well as the curve of ratio with respect to rate of flow. (Fig. 11.)

The level in the float chamber varied by not more than 0.1 inch for all flow rates, a negligible quantity when compared with the suction produced by the air flow. (See fig. 13.)

Carburetor No. 3 (*fig. 14*).—In this carburetor, which has a single air inlet only, a vertical cylindrical plunger, with its axis normal to the center line of the horizontal air passage, tends, by gravity, to choke the air. This is counteracted by the pressure on the upper side of the plunger, which—due to a small connecting passage—is identical with the pressure of the air or mixture after it has been throttled by the plunger. The plunger carries at its lower end the fuel metering pin, a cylindrical rod with a tapering groove cut into it. The metering pin dips into the cylindrical fuel aspirating tube, the end of which extends into the air passage, and which may be shifted up and down, thus providing for a hand adjustment.

The carburetor, therefore, belongs to new subclass 12.5.

Figures 15 and 16 show the air-gasoline ratio versus flow rate for five different throttle positions, figure 15 for 62.5° B. gasoline,



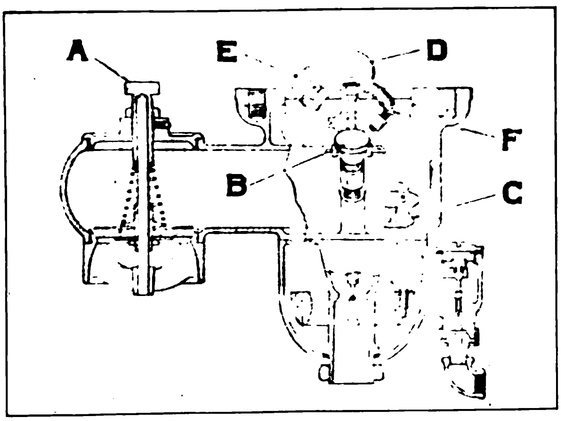


Fig. 10.—Carburetor No. 2.

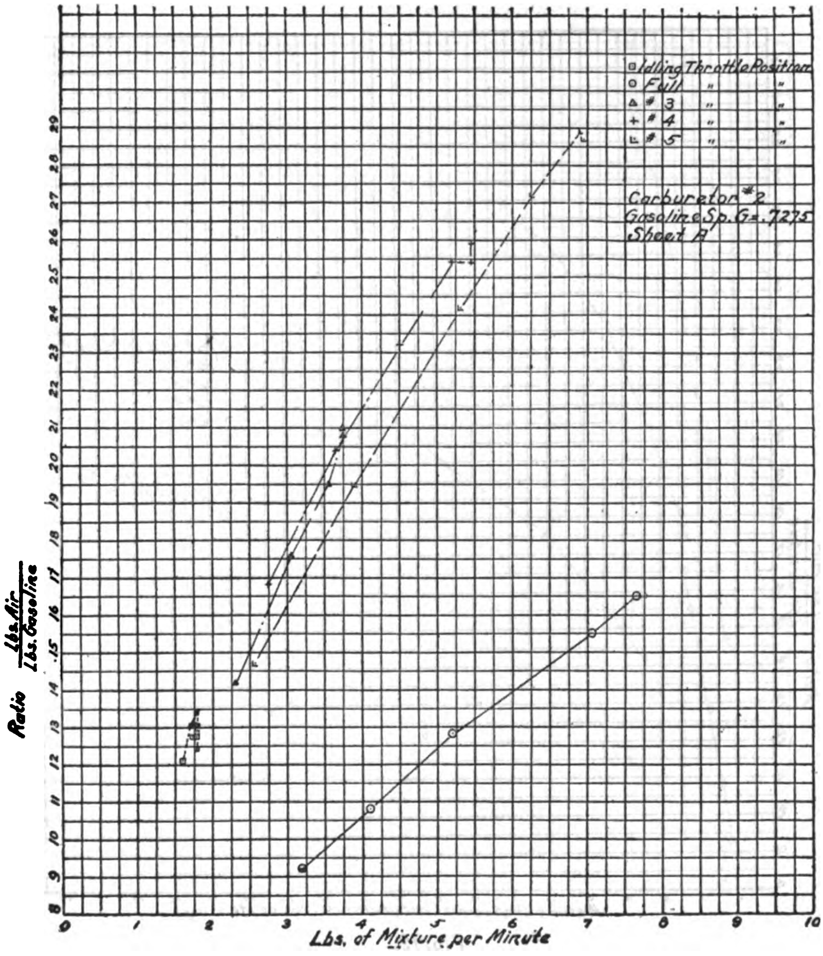

Idling Throttle Position
Full " "
3 " "
4 " "
5 " "
Carburetor #2
Gasoline Sp. G=.7275
Sheet A
Ratio Lbs. Air / Lbs. Gasoline
Lbs. of Mixture per Minute
0 1 2 3 4 5 6 7 8 9 10
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29

Fig. 11.

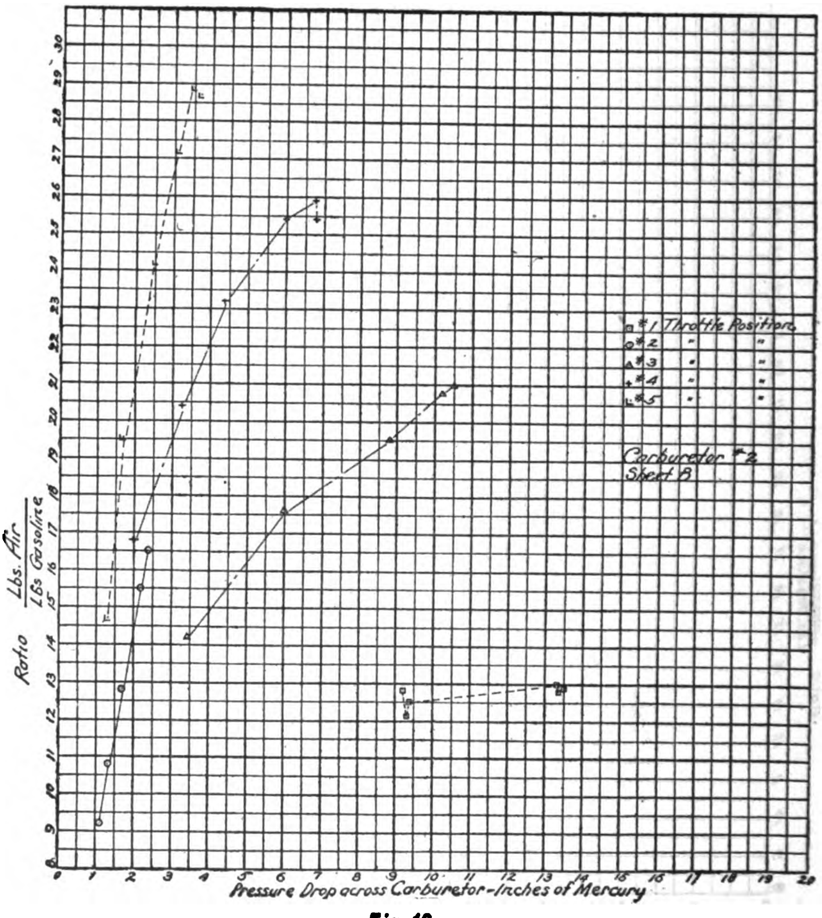

Ratio Lbs. Air / Lbs Gasoline
□ #1 Throttle Position
○ #2 " "
△ #3 " "
+ #4 " "
L #5 " "
Carburetor #2
Sheet B
Pressure Drop across Carburetor - Inches of Mercury

Fig. 12.

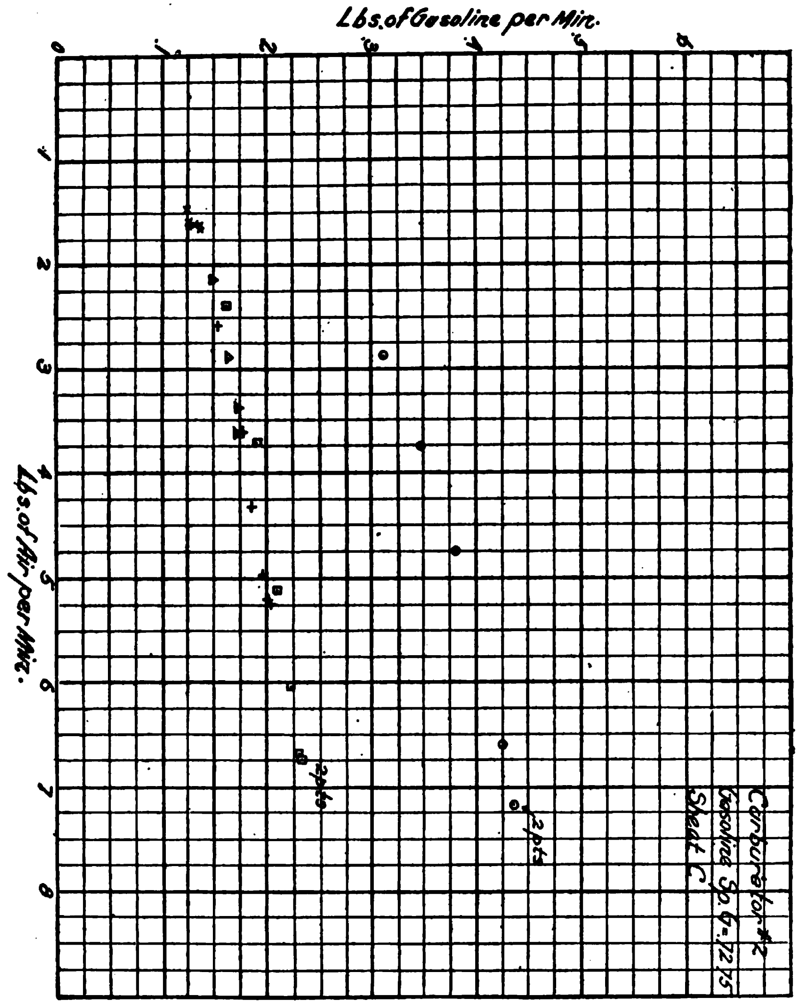

Lbs. of Gasoline per Min.
Lbs. of Air per Min.
Carburetor #2
Gasoline Sp. G. .7275
Sheet C
2 pts
2 pts

Fig. 13.

and figure 16 for 75° B. gasoline, or sheets A and A_2, respectively. An inspection of these curves gives the following results:

(*a*) From A, as well as A_2, it is seen that the maximum capacity of the carburetor should be taken as slightly more than 8.2 pounds of mixture per minute. This evidently represents the point where the plunger has risen as far as it can, and therefore ceases to regulate, and the carburetor becomes a fixed fuel-flow area, fixed air-flow area instrument. Consequently the mixture tends to become richer. Points beyond 8.2 pounds per minute of mixture will therefore not be considered.

(*b*) On A points of group No. 2 to represent the idling position of the throttle. Evidently the aspirating effect at the mouth of the nozzle is insufficient at such for flow rates. It is a general practice to use a very rich mixture when idling, but the carburetor shows just the opposite, a very much leaner mixture than for higher flow rates.

(*c*) Leaving out the idling position, the mixture on both A and A_2 is seen to become gradually leaner as the flow increases, and the air-gasoline ratio increases on A, from an average of about 14.5 to about 15.9, on A_2 from about 14.6 to approximately 16.2. This corresponds to mean values of 15.2 and 15.4, respectively, or the total variation in *average* ratios amounts to 9.2 per cent and 10.4 per cent, respectively, of the mean ratios.

(*d*) The discussion under (*b*) referred to average ratios. If, however, extreme values, low and high, are taken, A shows a range from 13.4 to 16.4, leaving out idling positions, and on A_2 from 10.6 to 16.8. True, this large variation is due to a few erratic readings, but there is no apparent reason why these readings should be thrown out. They are evidently due to the sticking of the plunger.

(*e*) The gradual increase in the air-gasoline ratio, as the flow increases, could be corrected by a change in the contours of either the tapering groove in the metering pin, or of the V-shaped bottom of the plunger, if the curves are to be flattened out.

Curve sheet B (fig. 17) will be discussed, in conjunction with the B curves of all the other carburetors, at the end of the test report.

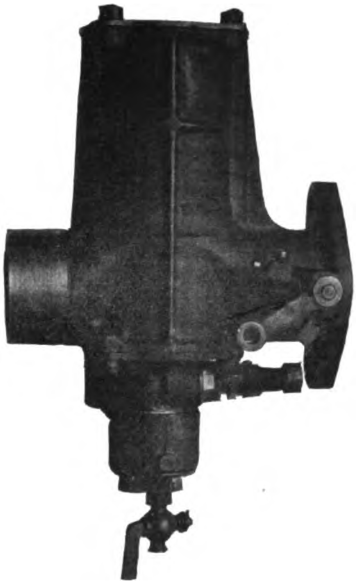
Figure 18 again proves that this method of representation fails to give to the eye a true picture of the irregularities of the operation, although it shows the nature of the equation representing the relation between air flow and fuel flow.

The variation in the float-chamber level was less than 0.1 inch, i. e., negligible.

Carburetor No. 4 (fig. 20).—In this carburetor the attempt is made by combining two carburetors one of which has a rising ratio versus flow curve and one with a drooping curve, so as by the simultaneous action to produce a horizontal ratio versus flow curve, i. e., a mixture of constant proportions. Or by accentuating the action of one component as compared with the other any desired tendency might theoretically be produced.

The carburetor has no moving parts whatever and adjustments of the mixture can only be made by exchanging nozzles or Venturi sections, excepting the idling device, which is independent of the rest of the carburetor and capable of adjustment.

A single air inlet is provided and two fixed fuel nozzles; the flow through one of the latter is controlled by the vacuum at its mouth,



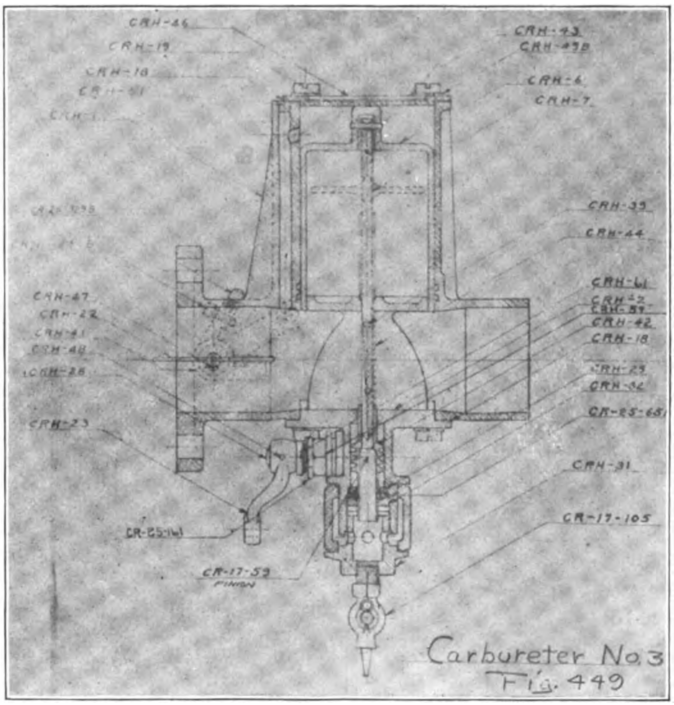
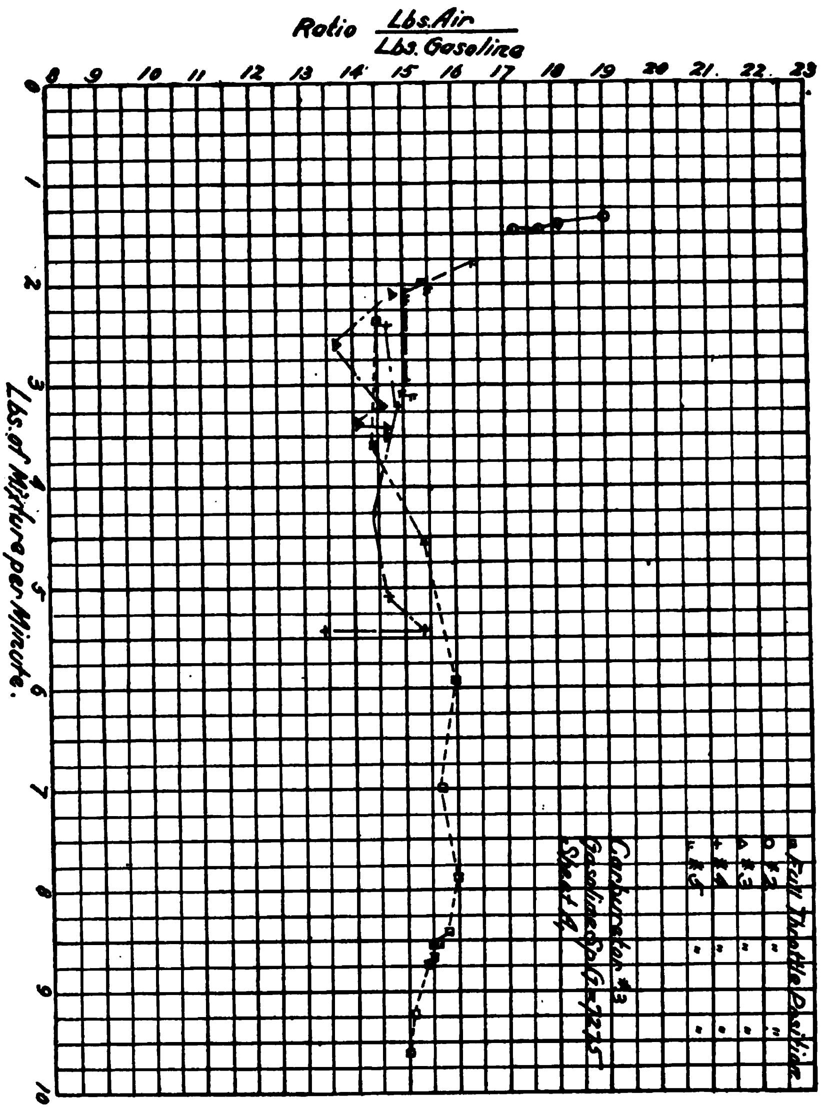
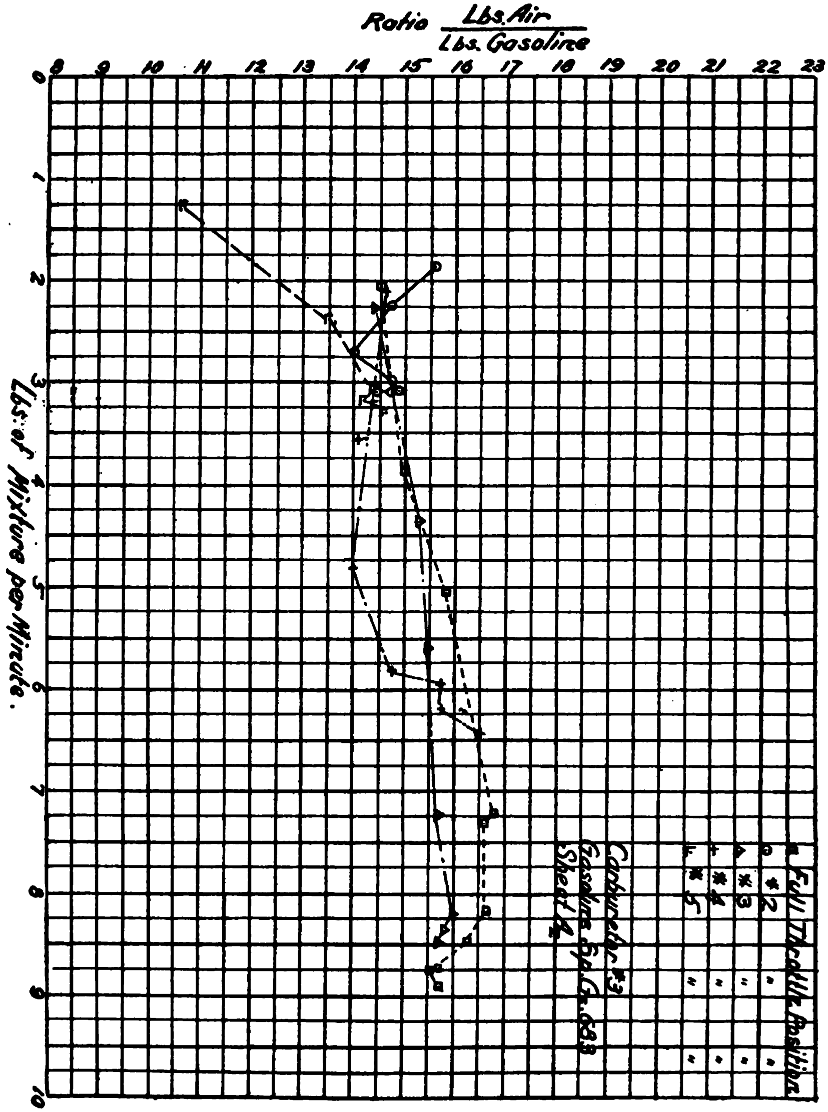


Fig. 14.—Carburetor No. 3.



Ratio Lbs. Air / Lbs. Gasoline
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
0 1 2 3 4 5 6 7 8 9 10
Lbs. of Mixture per Minute.
Carburetor #3
Gasoline Sp. G. = .7275
Sheet A.
Full Throttle Position

Fig. 15.



Ratio Lbs. Air / Lbs. Gasoline
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
0 1 2 3 4 5 6 7 8 9 10
Lbs. of Mixture per Minute.
Full Throttle Position
#2
#3
#4
#5
Carburetor #3
Sheet 4

Fig. 16.

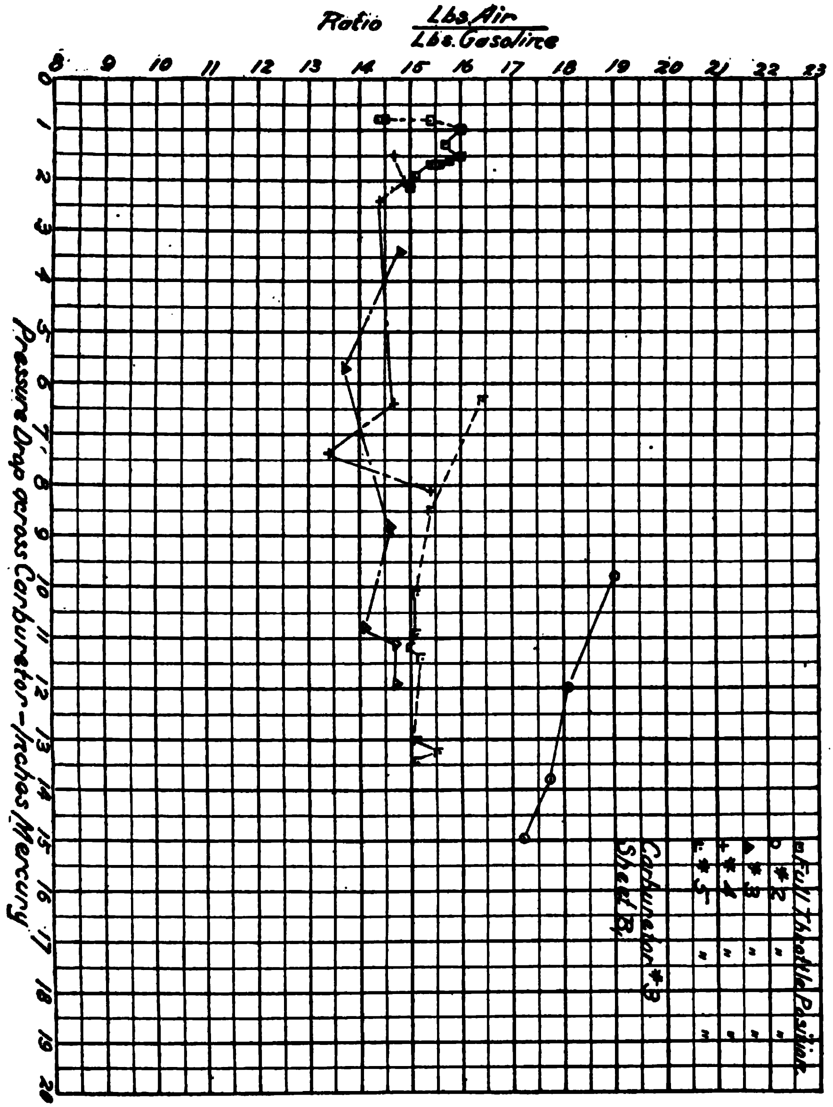

Ratio Lbs. Air / Lbs. Gasoline
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Pressure Drop across Carburetor - Inches Mercury
Carburetor #9
Shell B.
Full Throttle Position
#2 "
#3 "
#4 "
#5 "

Fig. 17.

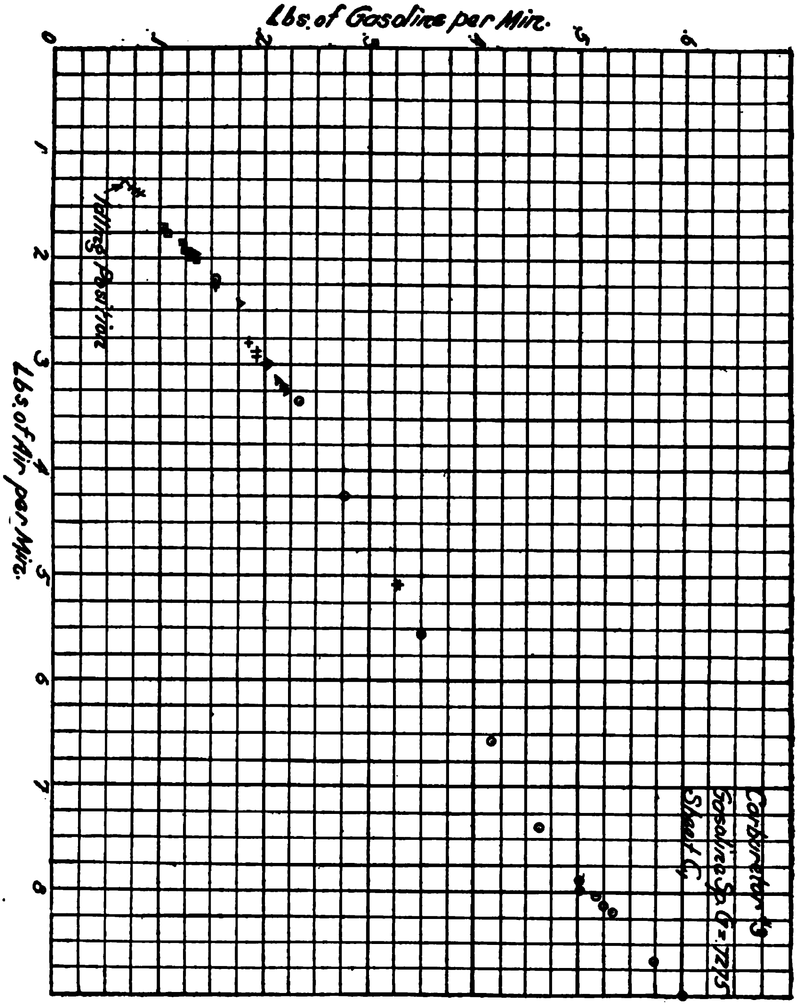

Lbs. of Gasoline per Min.
Lbs. of Air per Min.
Idling Position
Carburetor
Gasoline Sp. G. = .7275
Sheet

Fig. 18.

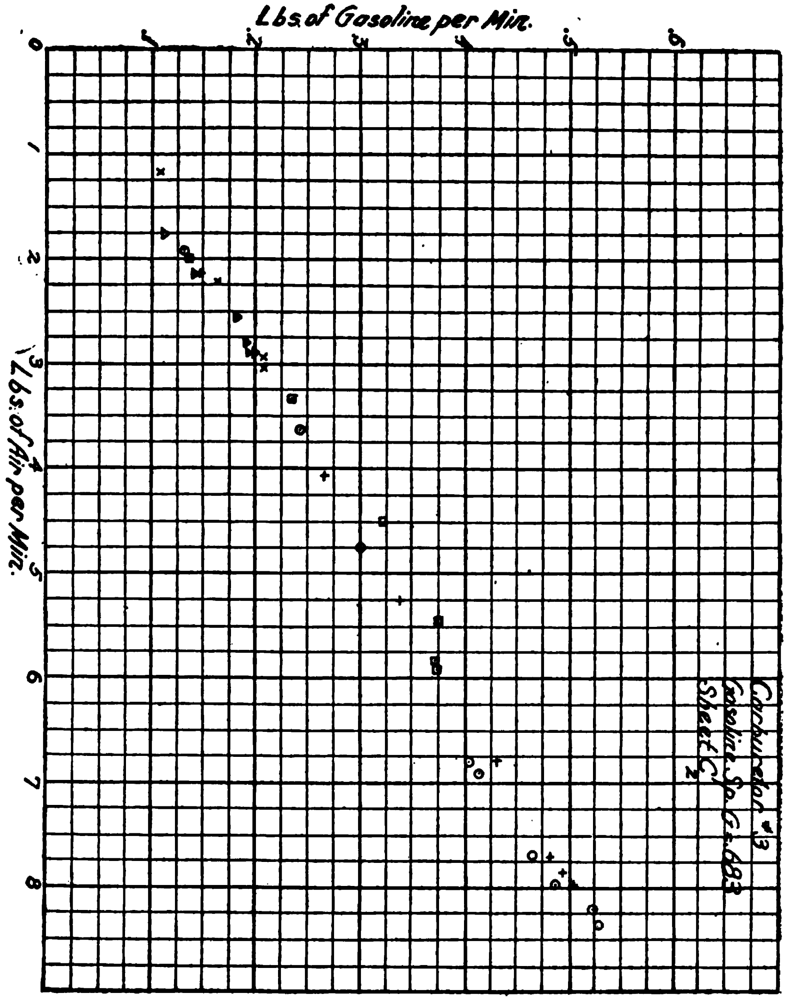

Lbs. of Gasoline per Min.
Lbs. of Air per Min.
Carburetor #3
Gasoline Sp. Gr. .683
Sheet C 2

Fig. 19.

while the flow through the other is limited by the amount which may pass into a well open to the atmosphere under a constant head. This arrangement places the carburetor into the new class 6.5.

When examining the results it should be noted that the carburetor is somewhat smaller than the rest of the instruments, as the list at the beginning of the test report shows. In this connection it may be remarked that the sizes 1¼ inches, 1½ inches, etc., as given in manufacturers' catalogues, do not accurately define the actual diameter of the discharge passage. Sometimes the actual diameter is less, in other cases it is greater than the list size, a custom which seems very unnecessary.

The results are plotted on figures 21–25, and figures 21 and 22 suggest the following comments:

(*a*) The action of the separate idling device is plainly seen in figure 21, where the points of group 2 represent this throttle position. Naturally these points could have been shifted downward, i. e., the mixture could have been made richer by adjusting screw O, figure 455. The variation in mixture proportions during idling is, however, considerable, between 18.4 and 20.7. This, of course, is not as important as the regulation for higher flow rates.

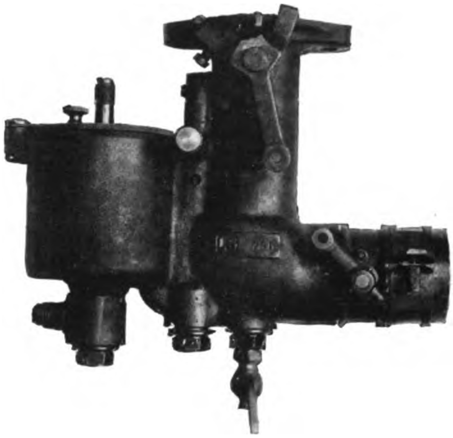
In figure 22, group 2, the throttle has been opened a little more than in test with the heavier gasoline and the main jets have begun to operate. Still the variation in the proportions is very large, between 13 and 15.5 in figure 22 (group 2) and between 13.8 and 16.9 in figure 456 (group 3).

(*b*) As the throttle is further opened, groups 4, 5, and full, the action becomes more regular. Conditions in the two tests agree quite closely. In each case the mixture gradually becomes leaner until a flow rate of about 4 pounds per minute is established. Between 4 pounds and 7 pounds the average remains constant at about 16.4 in each case, and 7 pounds of mixture per minute would seem to be the upper limit of the working range. At higher flow rates the mixture again becomes richer.

(*c*) The variation in mixture proportions for the same flow rate but different throttle positions is not large, comparatively, at least, except for the lower range of flow rates, i. e., below about 2.5 pounds of mixture per minute. For example, on figure 22, between 4 and 7 pounds' flow, the maximum variation is only 0.7 for an average ratio of about 16.3, corresponding to 4.3 per cent.

(*d*) If, however, the intention is to have a constant ratio through the whole working range, then the results must be looked at in a different manner. Leaving out group 2 in figure 456, the ratio in figure 21 ranges from 13.8 to 16.9 and in figure 22 from 13 to 16.7.

(*e*) The test results for this carburetor are of especial interest, since it is the only carburetor tested which has no moving parts, designed to regulate the proportion by their automatic operation, excepting carburetor No. 10, which has to be discussed by itself. Now, comparing all sheets marked "A" it will be plainly seen that No. 4 carburetor shows some irregularities and erratic tendencies, especially in the lower flow ranges, but nothing like some of the instruments, and none of them can be said to excel No. 4 in this respect. This again tends to substantiate the claim that those gross irregularities are due to sticking and binding of the moving parts. That at low-



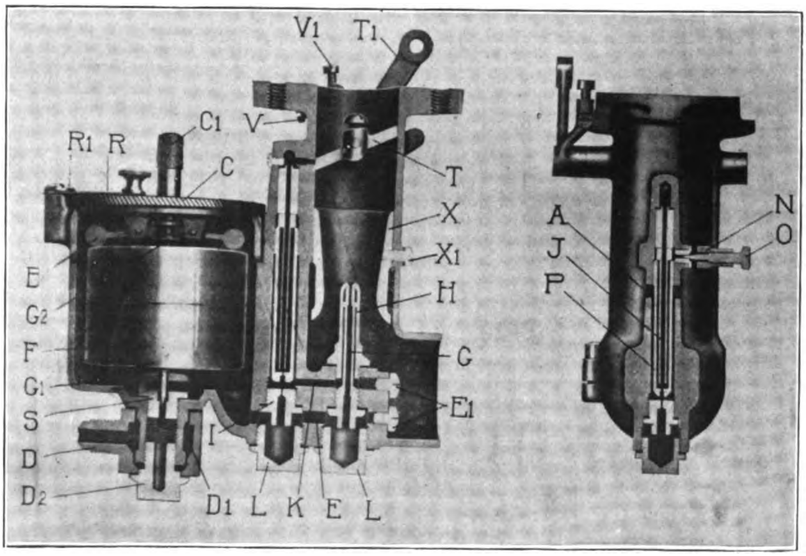


FIG. 20.—Carburetor No. 4.

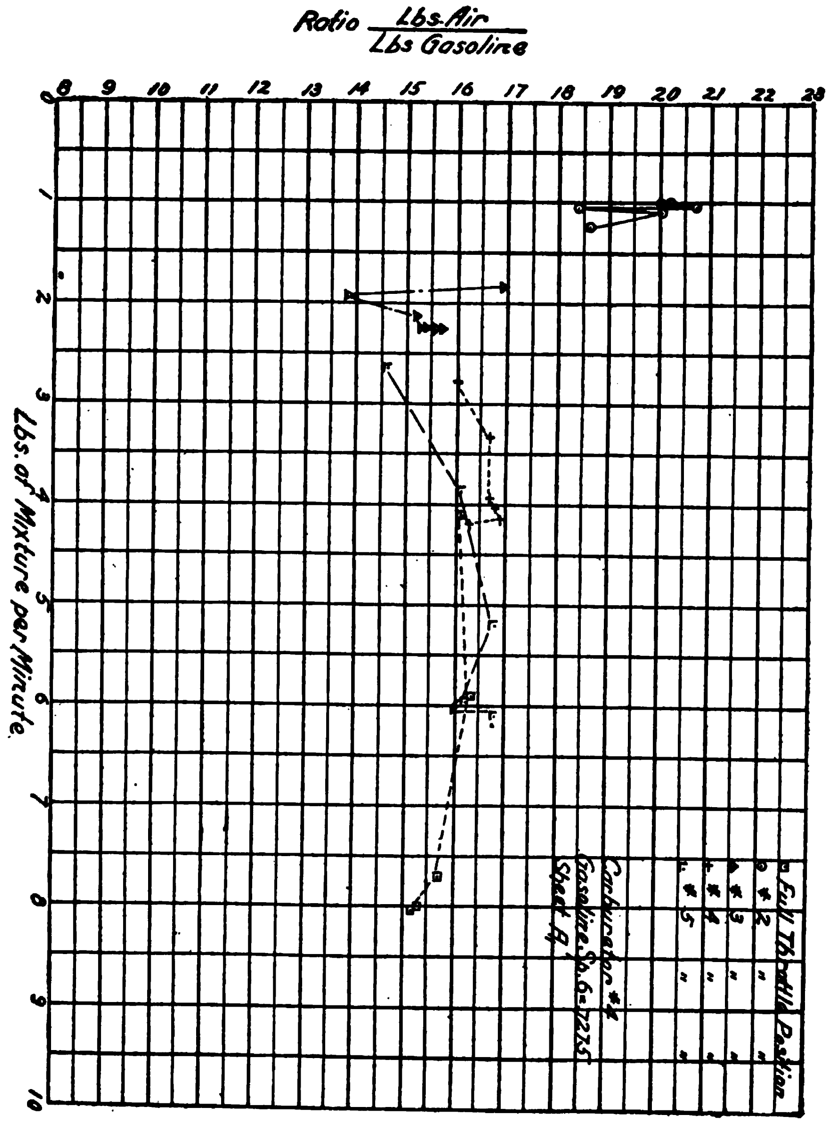

Ratio Lbs Air / Lbs Gasoline
Lbs. of Mixture per Minute.
0
1
2
3
4
5
6
7
8
9
10
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
□ Full Throttle Position
○ #2 " "
▶ #3 " "
+ #4 " "
⌐ #5 " "
Carburetor #4
Gasoline Sp. G.=.7235
Sheet A.

Fig. 21.

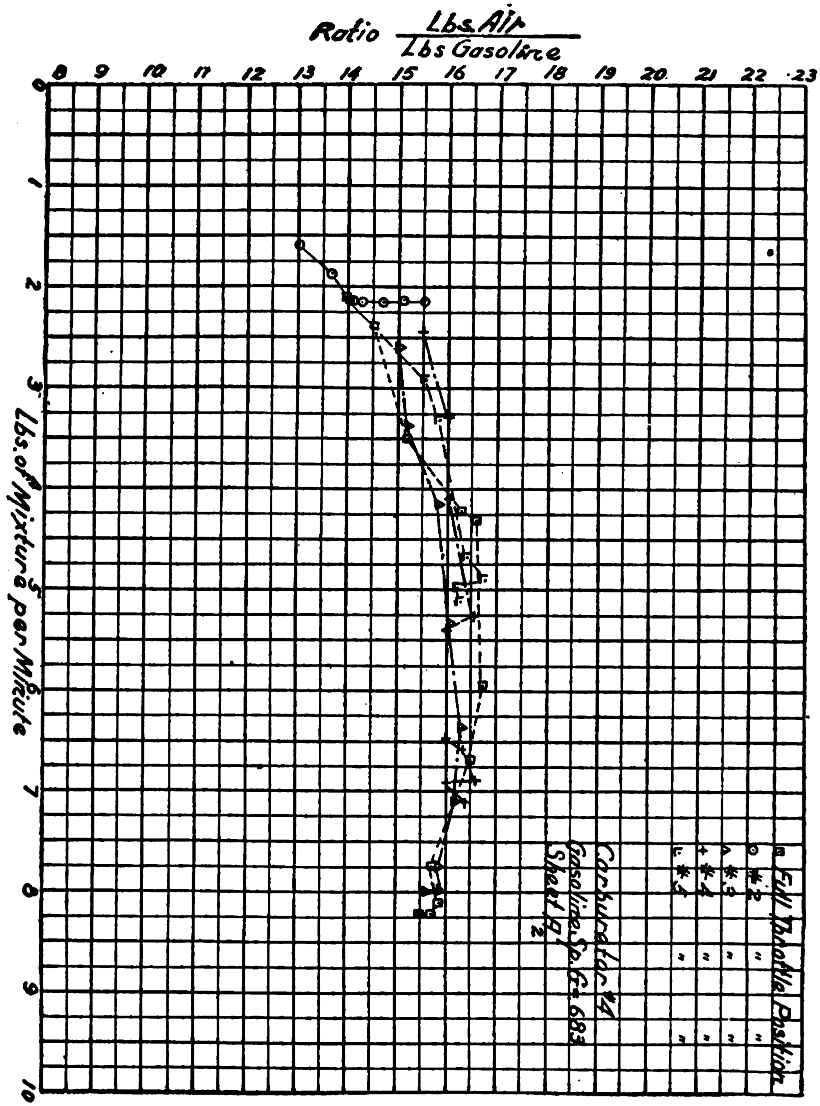
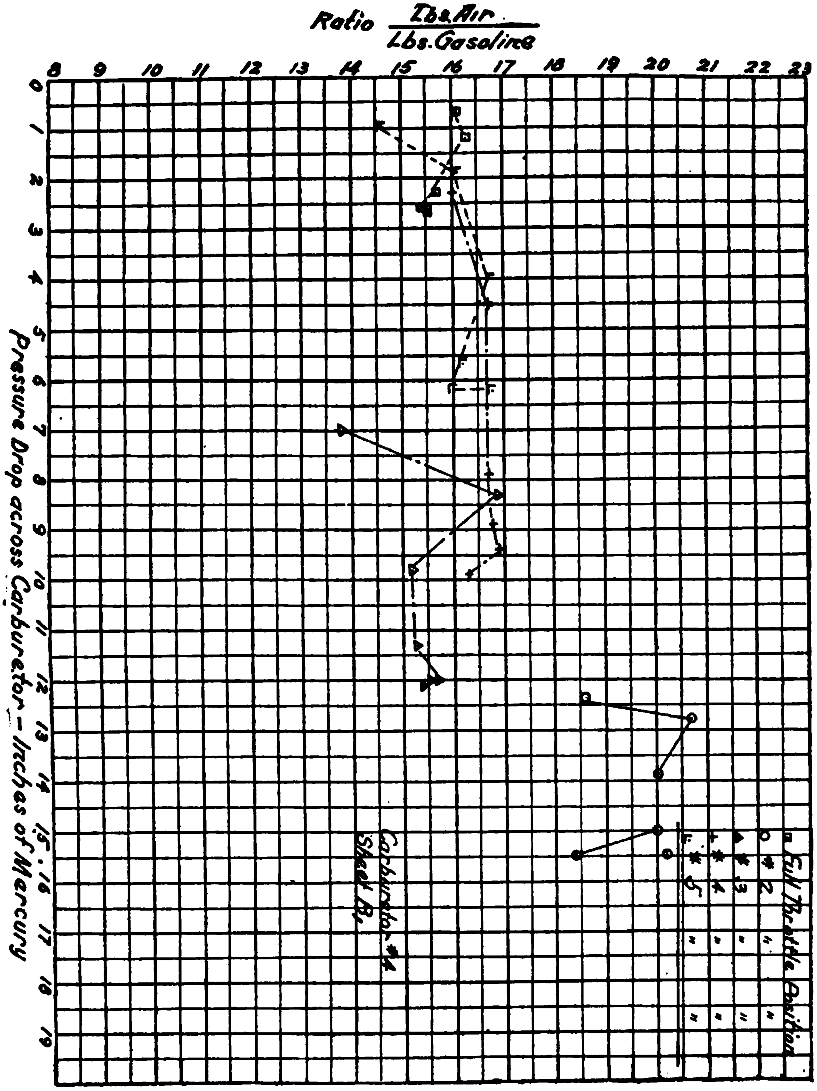

Ratio Lbs Air / Lbs Gasoline
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
0 1 2 3 4 5 6 7 8 9 10
Lbs. of Mixture per Minute
Full Throttle Position
#2
#3
#4
Carburetor #4
Gasoline Sp. G = .683

Fig. 22.



Ratio Lbs. Air / Lbs. Gasoline
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Pressure Drop across Carburetor – Inches of Mercury
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Carburetor #4
Sheet B1
Full Throttle Position

Fig. 28.

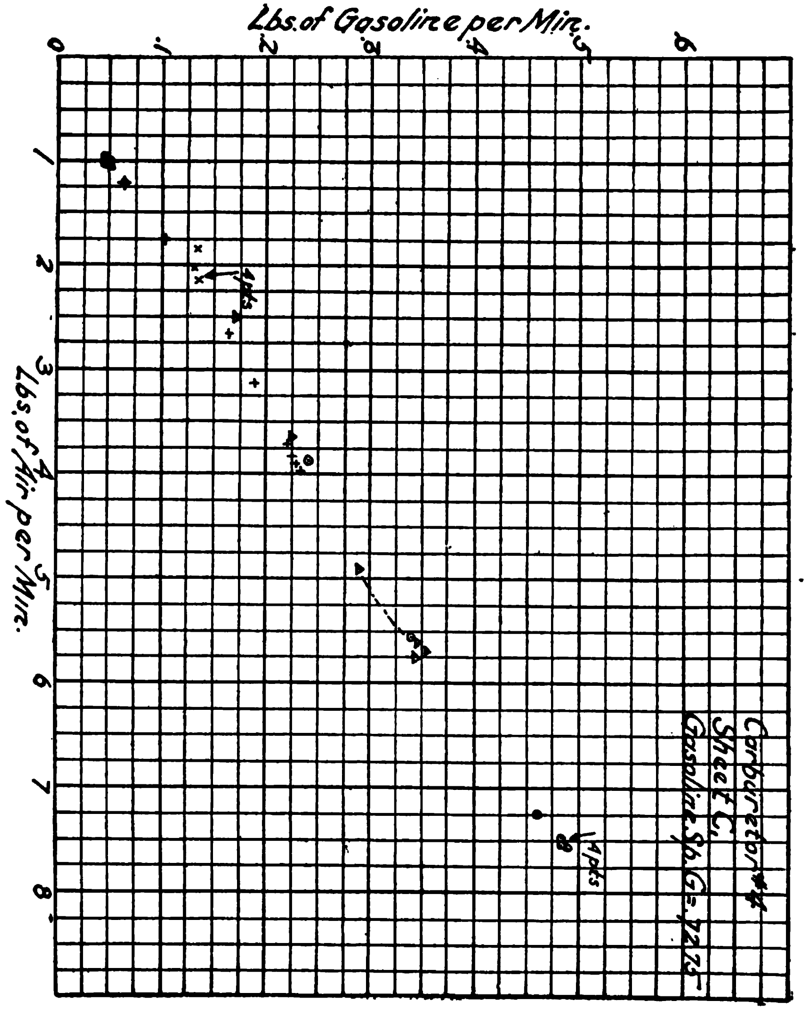

Lbs. of Gasoline per Min.
Lbs. of Air per Min.
Carburetor #4
Sheet C.

Fig. 24.

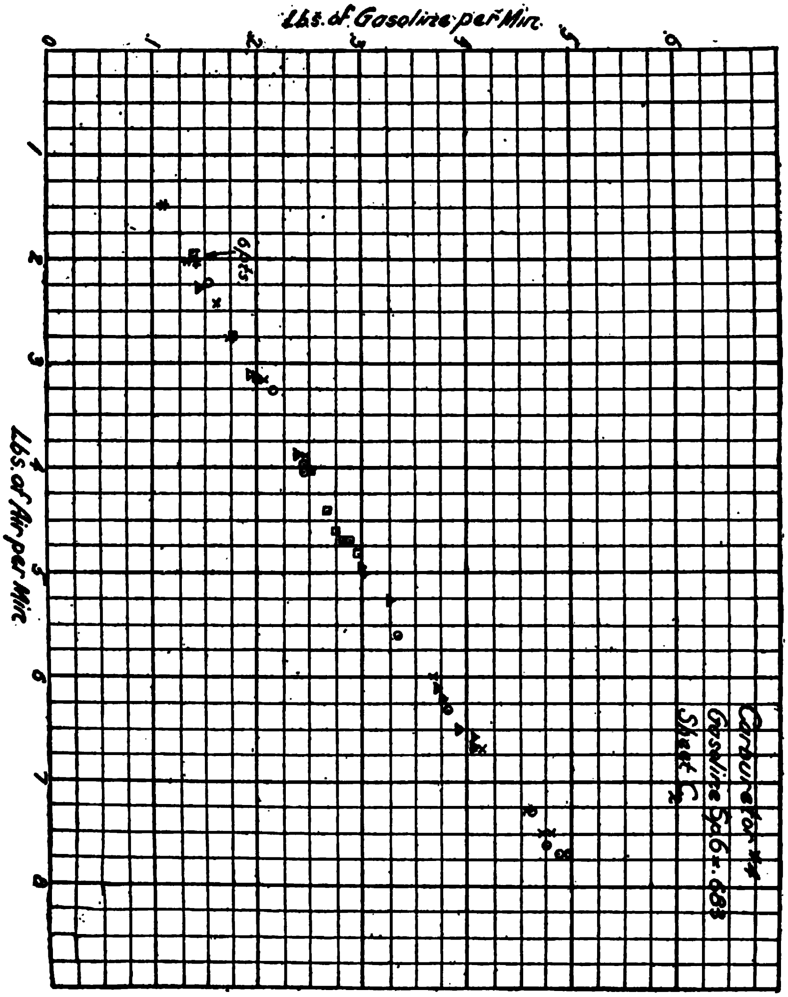

Lbs. of Gasoline per Min.
Lbs. of Air per Min.
Carburetor #4
Gasoline Sp.G. = .683
Sheet C2

Fig. 25.

flow rates all of the carburetors exhibit erratic tendencies is not surprising at all, since it is well known from hydraulics that flow through orifices under low heads is apt to be erratic.

(*f*) As mentioned before, the curves could be changed in character by substituting a compensating nozzle of a different size, but whether the average ratio could be thereby made constant over a larger range of flow rate is questionable, since for low-flow rates the atmospheric well must be partly filled with fuel, so that the discharge is not constant. A peculiar "hysteresis" action is claimed by the makers for this intermediate state of affairs, but this can not be discussed here.

Sheet B, figure 23, will be discussed later.

Figures 24 and 25 show very plainly the general tendency of the variation in air-gasoline ratio, but nothing more.

The gasoline level in the float chamber varied as much as 0.45 inch between no flow and maximum flow (see log sheets, pp. 506 and 507), which seems unduly high, but this large drop took place only at the highest flow rates where, according to figure 54, the suction at the mouth of the nozzle rises as high as 64 inches of water, equal to about 87 inches of gasoline, so that the percentage of the total flow head is small.

Carburetor No. 5 (*fig. 26*).—The carburetor is similar in principle to No. 3 and belongs to the same class, new class 12.5. In this case, however, the metering device consists of a guided poppet valve "floating" in the currents of air, all of which enters through a single inlet. The tapered metering pin is stationary and the aspirating tube rises and falls with the metering valve, being located in the core of the latter. An important distinction, as compared with No. 3, is that the whole metering pin and the surrounding part of the aspirating tube are wholly immersed in the fuel, so that a submerged orifice determines the quantity of fuel. The metering pin may be adjusted up and down by hand until the desired mixture is obtained. A dashpot plunger at the lower end of the metering valve stem is immersed in the fuel.

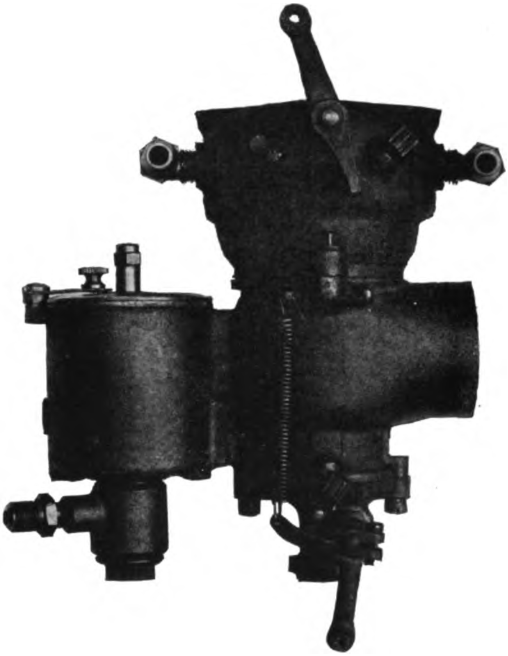
Since at low-flow rates the metering valve does not lift from its seat, small air passages are provided in the body of the valve, as figure 461 plainly shows, and these passages, leading past the mouth of the aspirating tube, provide the mixture for running the engine until the suction is sufficient to lift the valve.

The results are plotted in figures 27–31, and suggest the following comments:

(*a*) On both figures 27 and 28 the conditions during idling are represented by groups 2 in the lower left-hand corners. The mixture is rich, as is generally demanded, and it varies between wide limits, as in the case in all carburetors having a separate idling arrangement.

(*b*) In both tests the general tendency is for the mixture to become leaner, until the air-gasoline ratio reaches a maximum between 3 and 4 pounds per minute. The mixture then slowly becomes richer, until at about 8.5 pounds per minute, when the gasoline begins to increase much faster than the air. This is probably the point where the metering valve gives maximum port opening so that the air inlet becomes fixed.

(*c*) The mean mixture for different throttle positions between about 16 and 19 on A_1 and 14.8 and 18 on A_2, but there are some enormous variations for the same flow rate at different throttle positions. Thus, in figure 28, at 1.5 pounds flow, the ratios are 12.2, 13.2, and



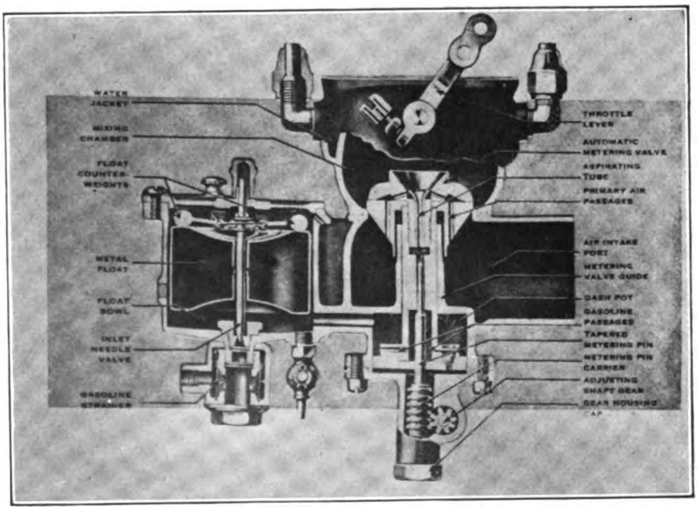


FIG. 26.—Carburetor No. 5.

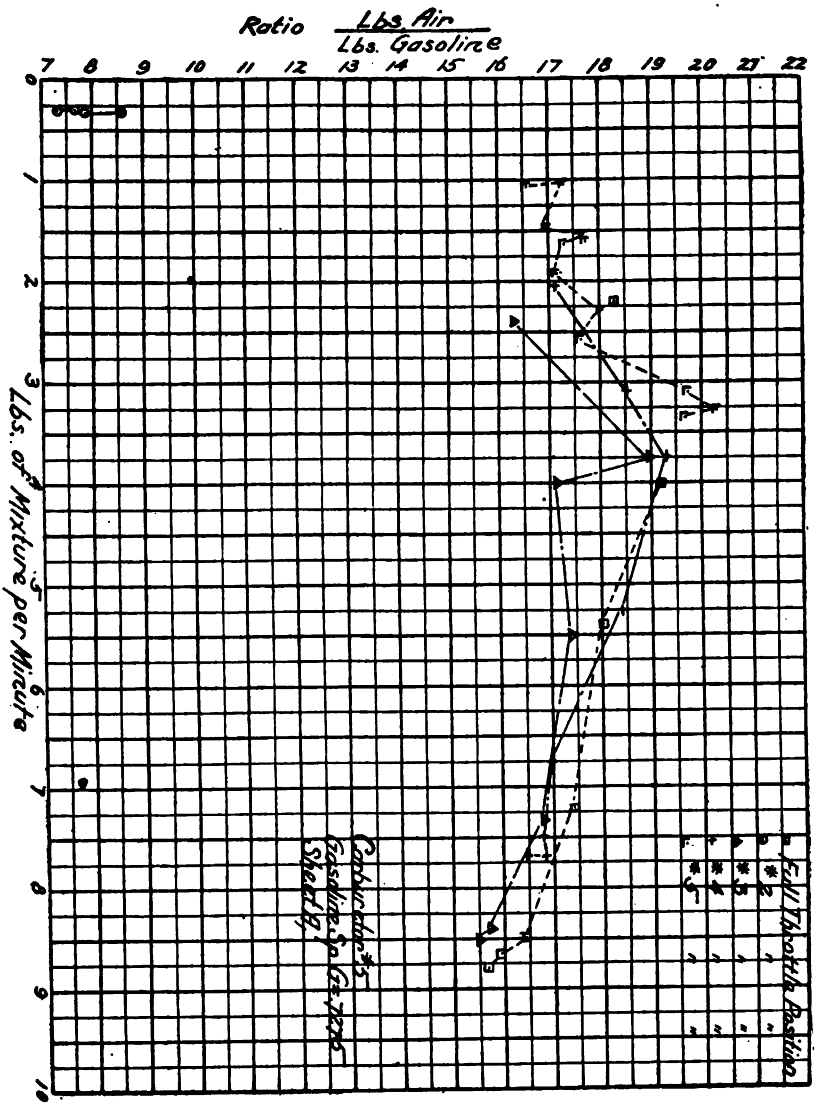

Ratio
Lbs Air
Lbs. Gasoline
7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
Lbs. of Mixture per Minute
Full Throttle Position

Fig. 27.

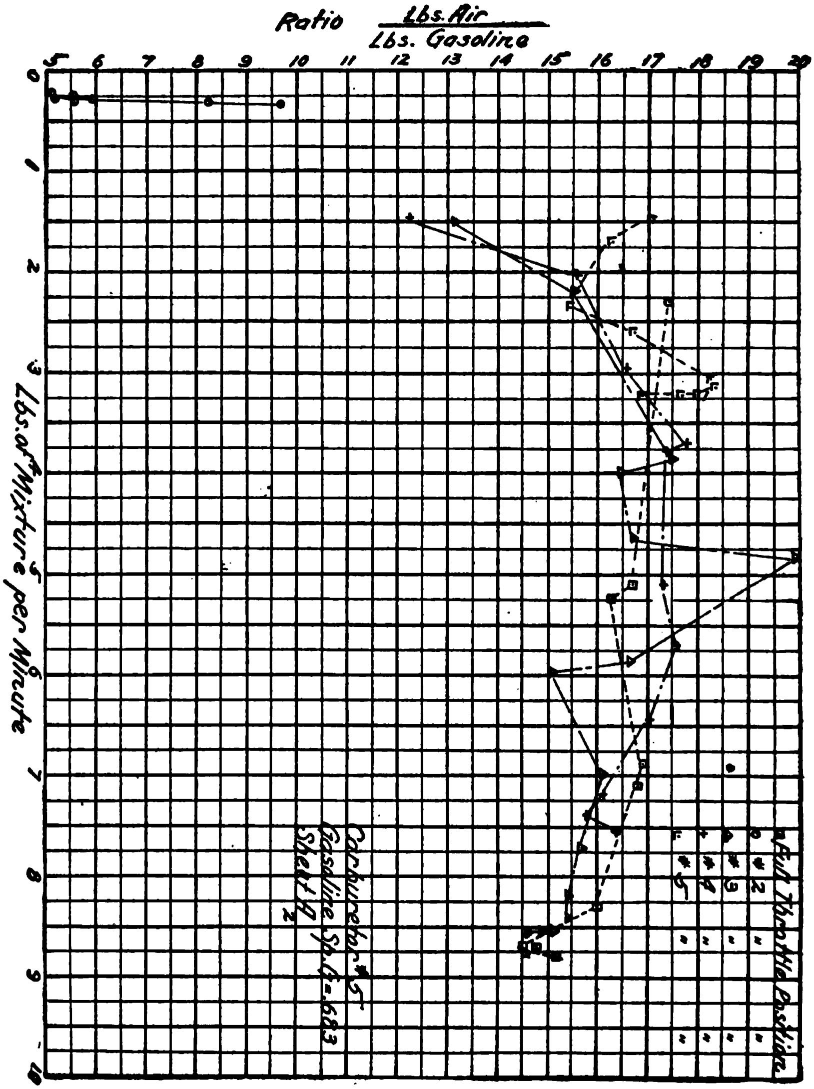

Ratio Lbs. Air / Lbs. Gasoline
5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
0 1 2 3 4 5 6 7 8 9 10
Lbs. of Mixture per Minute
Carburetor #5
Gasoline Sp. G. = .683
Sheet 4 1/2
Full Throttle Position
#2
#3
#4
#5

Fig. 28.

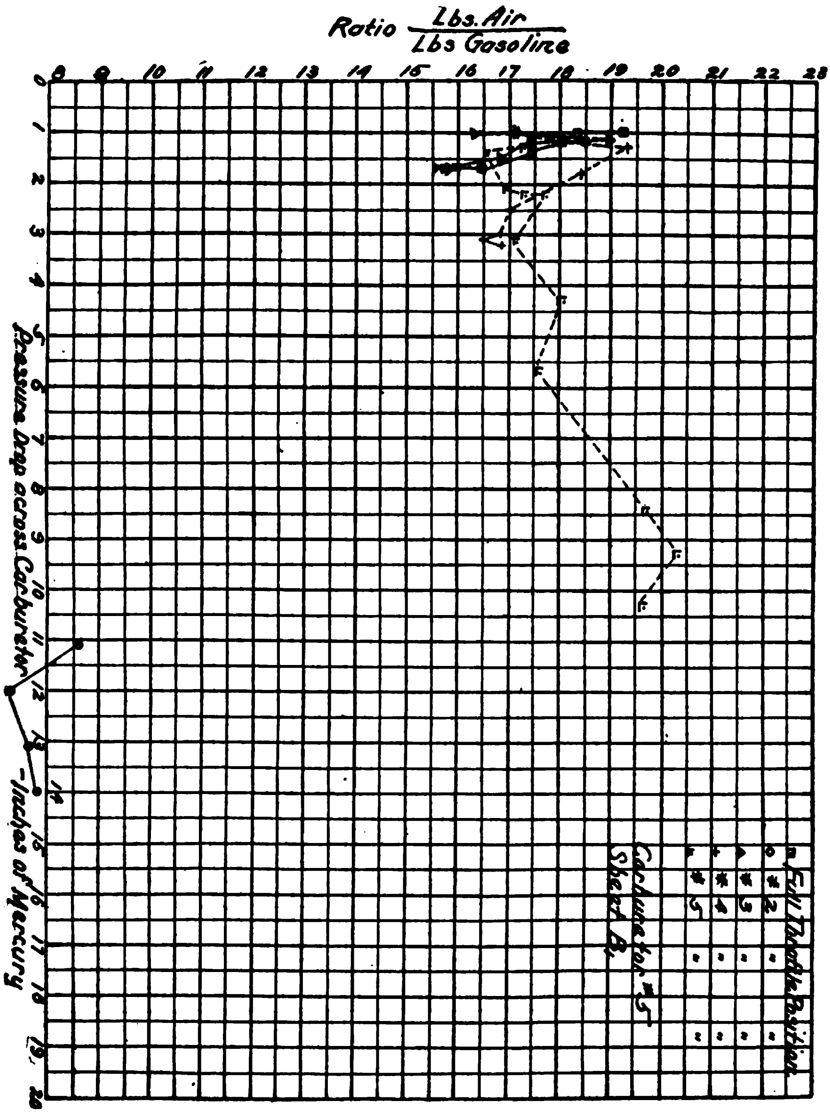

Ratio Lbs. Air / Lbs Gasoline
Pressure Drop across Carburetor -Inches of Mercury
Full Throttle Position
#2
#3
#4
#5
Carburetor #5
Sheet B.

Fig. 29.

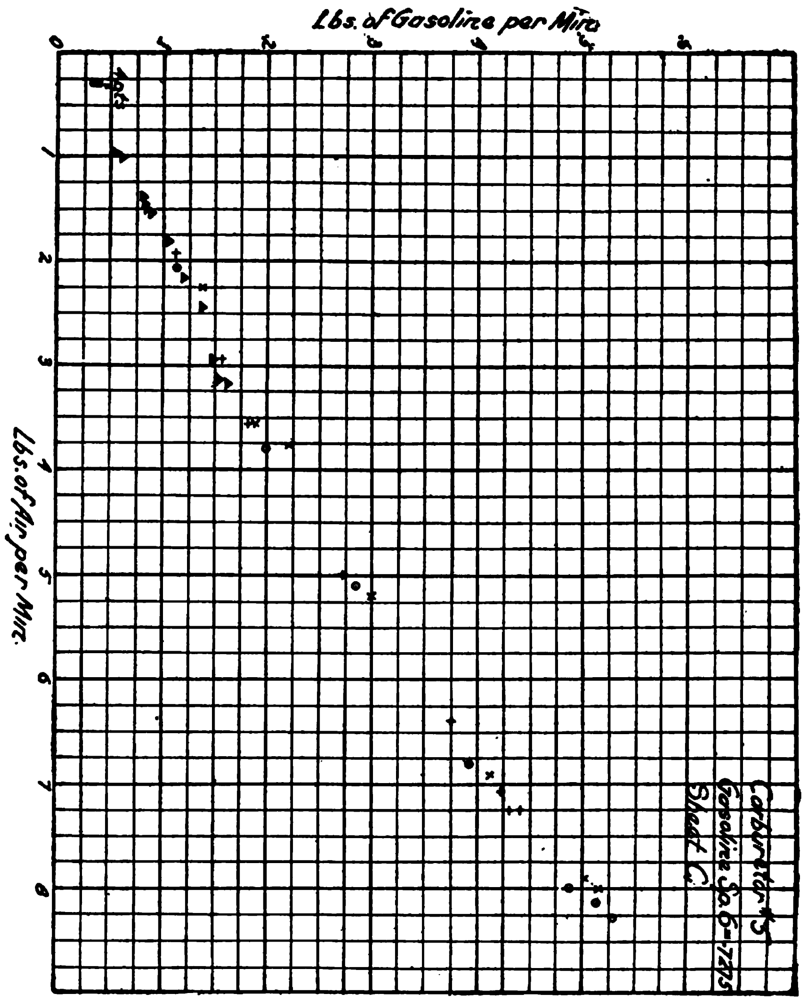

Lbs. of Gasoline per Min.
Lbs. of Air per Min.
Carburetor #3
Gasoline Sp. G.=.7275
Sheet C.

Fig. 30.

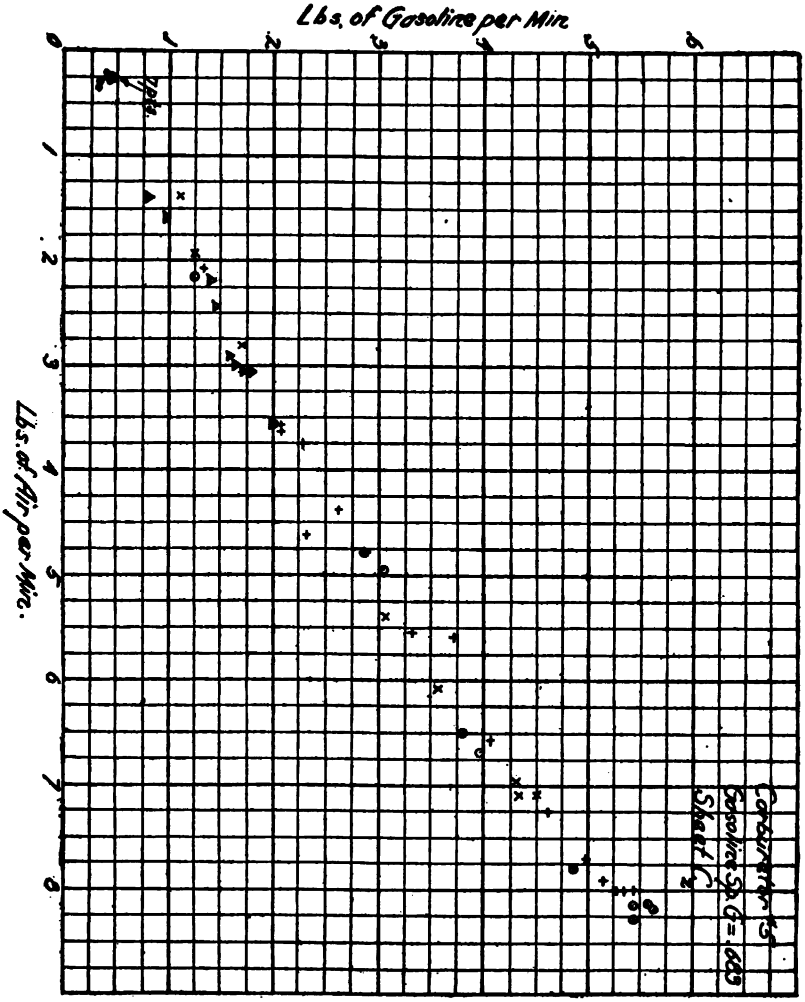

Lbs. of Gasoline per Min.
0
1
2
3
4
5
6
7
8
Lbs. of Air per Min.
Carburetor
Gasoline Sp. G = .683
Sheet C

Fig. 31.

0.17 for throttle positions 4, 3, and 5, respectively. This corresponds to a total variation of 4.8, or 34 per cent, referred to the mean, 14.1.

At 7 pounds flow, on the other hand, in the same test, the variation for three throttle positions is only 0.75 for a mean value of 16.3, or 4.6 per cent. Only the irregular action of the metering valve, due to sticking and sluggishness, can account for such discrepancies.

(*d*) Whether the general tendency of all curves, especially the gradual enriching of the mixture with increase in flow, is desirable in a carburetor need not be discussed here. A modification of the outlines of the metering valve would evidently change the characteristics of the ratio versus flow curve, at least as far as the part to the right of the peak is concerned.

Sheets C_1 and C_2, figures 30 and 31, very clearly and much better than A_1 and A_2, show the effect of the fuel density on mixture proportions. More about this will be said later.

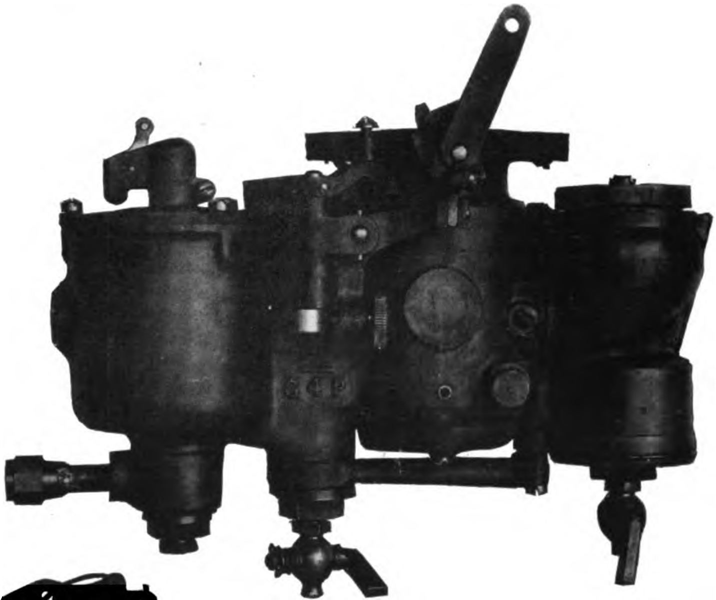
The level in the float chamber remained practically constant under all conditions, a maximum variation of 0.1 inch being negligible.

Carburetor No. 6 (*fig. 32*).—As may be seen in the cross section, this carburetor has three air inlets, one constant and the other two provided with spring-loaded automatic valves. The latter two are interconnected by linkwork, and one of them operates a tapered metering pin for gasoline. Another spray nozzle is in the constant air opening and is the only one in operation until the automatic air valves begin to open. A dashpot piston submerged in gasoline dampens the motion of the automatic air valves. Adjustments for both spray nozzles are provided. Thus the carburetor is seen to belong to new class 14.1.

Inspection of curve sheet C_1, figure 35, demonstrates that the carburetor was adjusted for the test so as to give constant average proportions, since means values are on a straight line passing through the origin, excepting for higher flow rates, beginning with about 4 pounds per minute, where the mixture begins to become slightly leaner. Whether the average ratio could have been made constant for the whole range of flow rates by means of the "high-speed" adjustment can not be stated with certainty.

Sheets A and B, figures 33 and 34, however, show that while the general tendency was to produce constant proportions the ratio actually varied between very wide limits. Whether it is mechanically possible to obtain perfectly free motion with so many moving parts and joints remains to be proven. In the absence of any other satisfactory explanation the test results would seem to indicate that it is not possible. This conclusion receives confirmation from the results of the tests for pressure at the mouth of the spray nozzle. If these results are plotted to a larger scale than the one used in figure 56, or if the log on Table IX is carefully examined, it is plainly seen that the suction increases more or less irregularly with the air flow, thus accounting for the variations in the gasoline-air ratio. When the air-gasoline ratio fluctuates in the extraordinary manner exhibited in figure 33, with a range extending from 11.9 to 17.2, it does not seem to be worth while to discuss mean values, as long as it is not shown that the excessive variation is not unavoidable with such elaborate mechanism.

The variations of the level in the float chamber were negligible, 0.15 inch being the maximum depression.



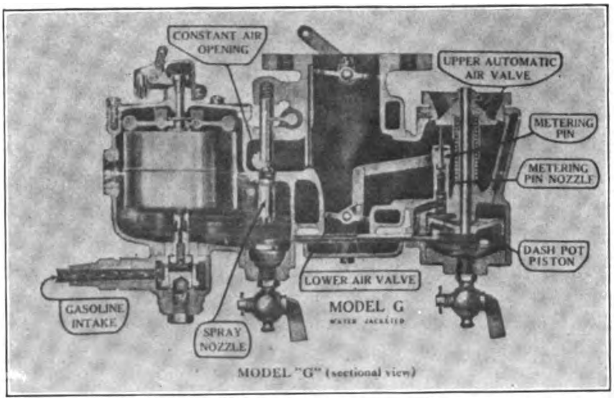


FIG. 32.—Carburetor No. 6.

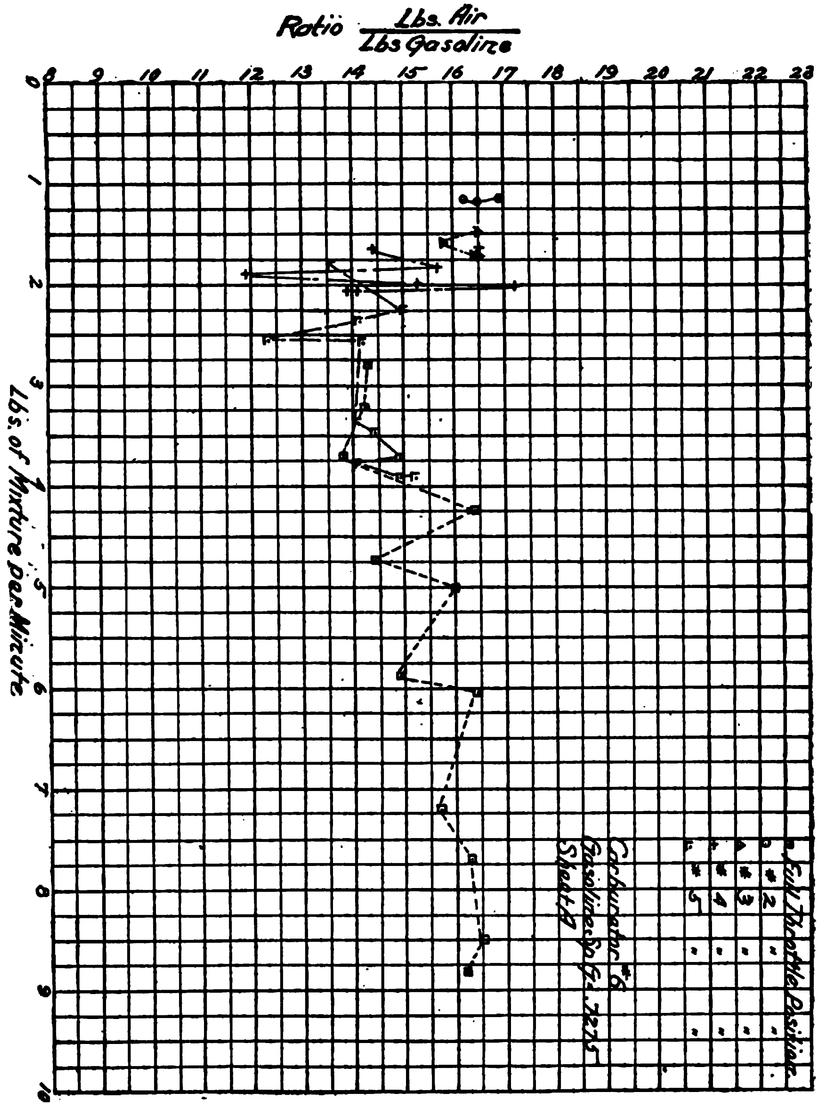

Ratio Lbs. Air / Lbs Gasoline
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
0 1 2 3 4 5 6 7 8 9 10
Lbs. of Mixture per Minute
Full Throttle Position
#2
#3
#4
#5
Carburetor #6
Gasoline Sp. Gr. .7275
Sheet 7

Fig. 33.

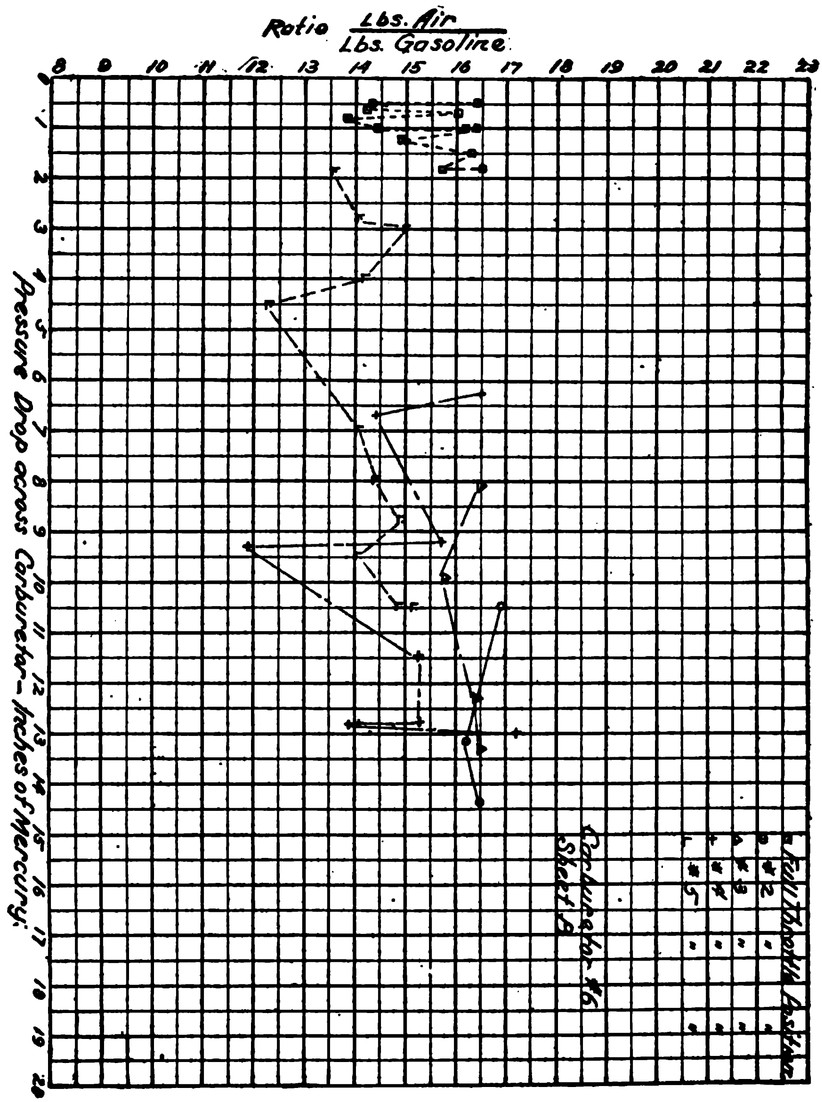

Ratio Lbs. Air / Lbs. Gasoline
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Pressure Drop across Carburetor—Inches of Mercury.
Carburetor #6 Sheet B
Full Throttle Position
#2
#3
#4
#5

Fig. 34.

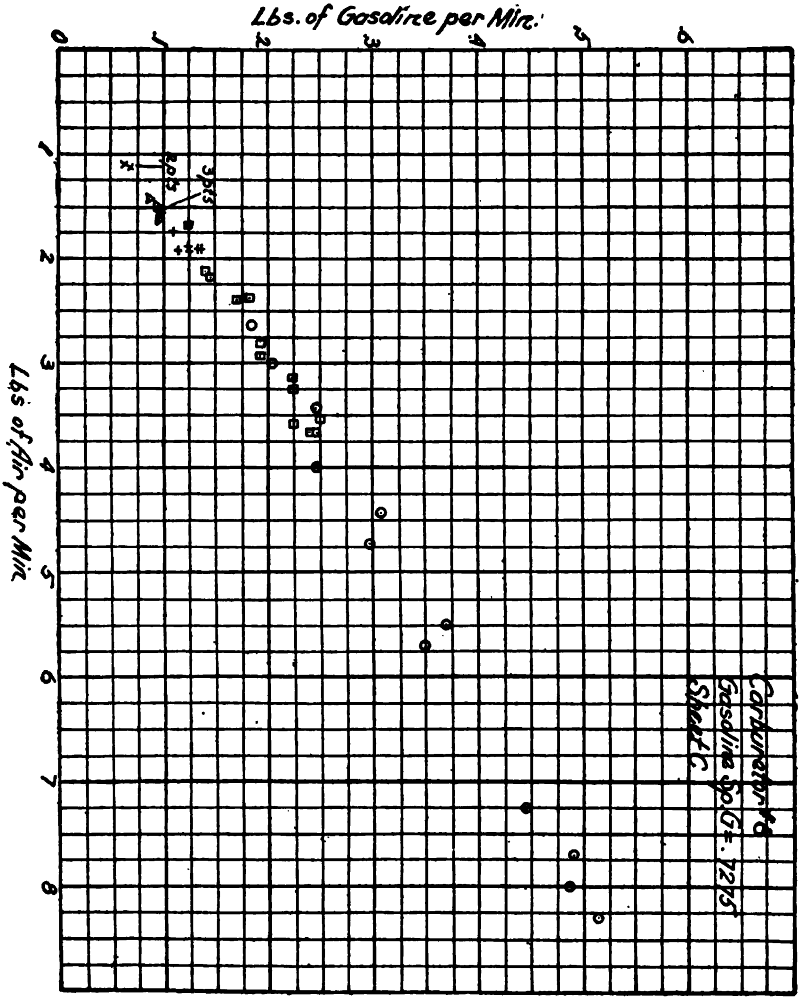

Lbs. of Gasoline per Min.
Lbs of Air per Min.
Carburetor #6
Gasoline Sp.G. = .7275
Sheet C.

Fig. 35.

Carburetor No. 7 (*fig. 36*).—In this carburetor, which has a fixed primary air inlet and a single-spray nozzle, hand adjusted by means of a needle valve, the auxiliary air enters through ports which are kept closed by bronze balls, until the suction is sufficient to raise them from their seats. After that the balls are kept floating in the air by the air flow, thus taking the place of springs such as used in the original Krebs type carburetors, but having the advantage over springs that the load never varies. This construction places the carburetor in new class 8.2.

Comments on results:

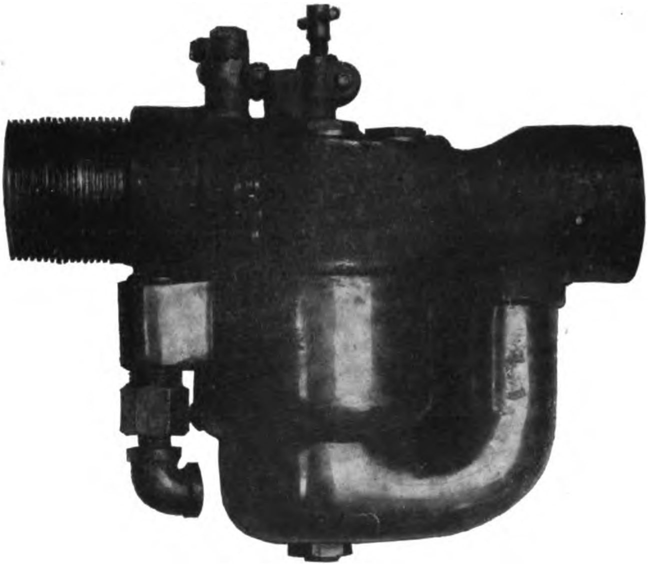
(*a*) According to the curves on figures 37–41, the compensating balls evidently do not begin to operate, at least not effectively, until, for this size carburetor, about 4 pounds of mixture per minute pass through. After this point has been reached the mixture maintains constant proportions, if mean values are taken, i. e., the curves representing mean values in figures 37 and 38 are horizontal lines, and in figures 40 and 41 straight inclined lines passing through the origin. The range, however, within which all the points are confined is between 7 and 10 per cent of the mean, in some places less.

(*b*) There must be a point where the balls cease to compensate, but the curves show hardly any falling off of the air-gasoline ratio.

(*c*) The suction at the outlet of the fuel nozzle does not increase with the flow in an absolutely regular manner as the curve on figure 55 and the log in Table X prove. This, of course, accounts for fluctuations in the mixture ratio. The only plausible explanation would seem to be that the balls (there are five of them) which are naturally not guided, do not act with absolute positiveness, although they have, of course, the advantage of total absence of friction.

(*d*) As in other carburetors there is an enormous variation in the mixture proportions at low-flow rates, and especially when the low-flow rate is due to the partial closing of the throttle rather than low engine speed. In this connection see groups 3 in figure 37 and groups 3 and 4 in figure 38. In the latter case for instance (group 4) the mixture flow increases from 2 to 3.6 pounds only, but the ratio increases proportionally to the flow from 9.1 to 14.2, an increase of 56 per cent. Group 4 represents an almost closed throttle position, and as the log readings No. 328 to 334 show, the pressure drop across the carburetor increased from 2.6 to 12.4 inches of mercury. These conditions would be reproduced by an automobile running on a smooth road offering little resistance and with varying degrees of down grade. In an aeroplane engine the higher flow rates would hardly ever be reproduced. The results show that under such conditions every carburetor tested fails to maintain even approximately constant mixture proportions, and that in every case the air to gasoline ratio increases more or less rapidly with the flow. Since at the same time the suction in the inlet manifold increases, the mixture should, if anything, become richer to allow for valve-stem leakage and decreased compression in the cylinder.

(*e*) The variation of the float chamber level was negligible with a maximum depression of 0.1 inch.



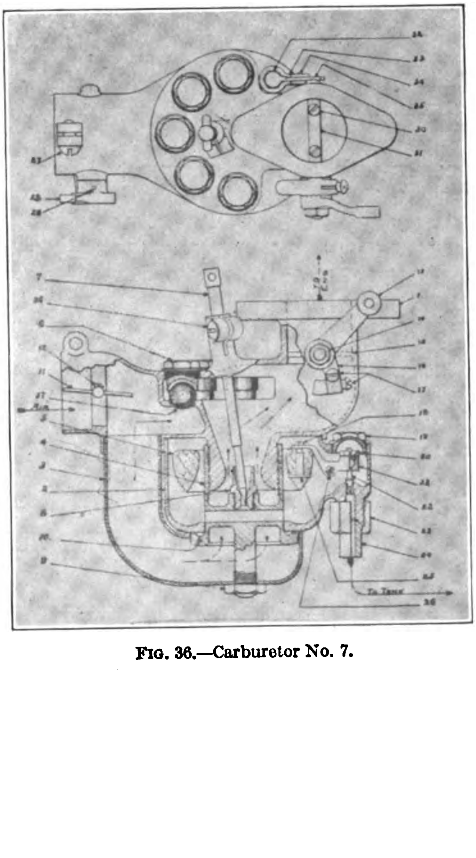


FIG. 36.—Carburetor No. 7.

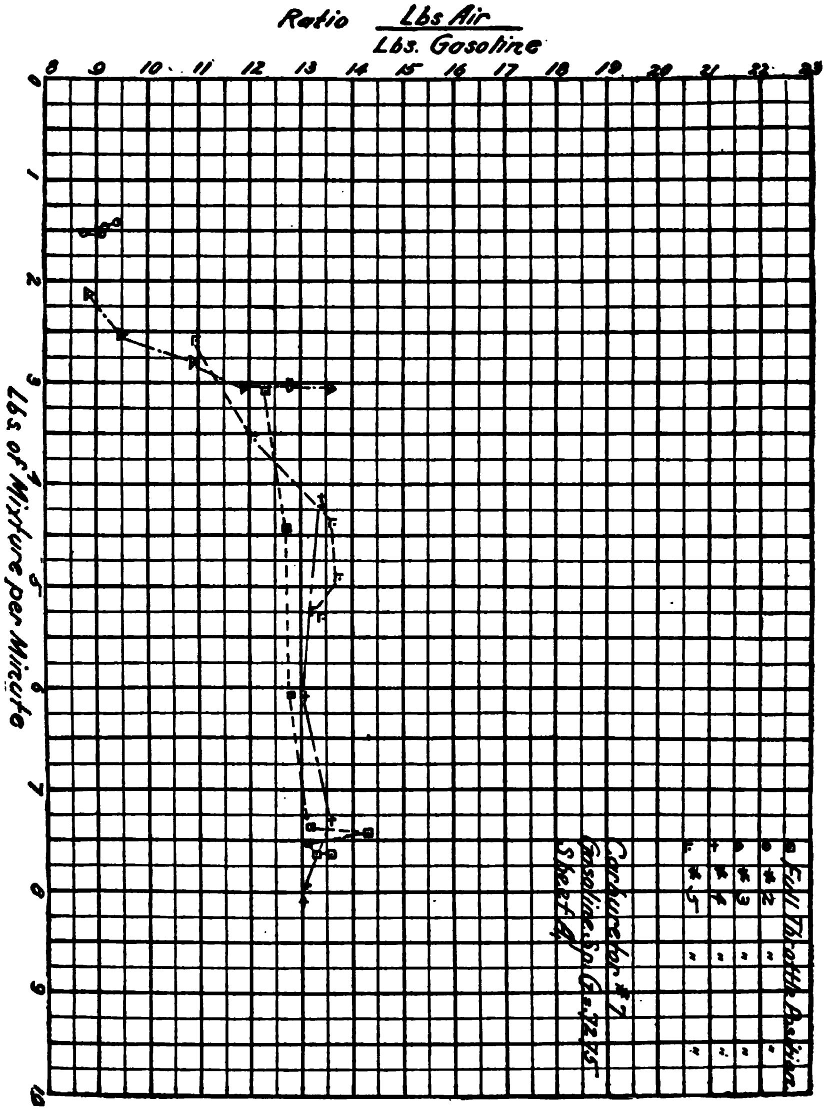

Ratio Lbs Air / Lbs. Gasoline
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Lbs of Mixture per Minute
0 1 2 3 4 5 6 7 8 9 10
Full Throttle Position
#2
#3
#4
#5
Carburetor #7
Sheet 4

Fig. 37.

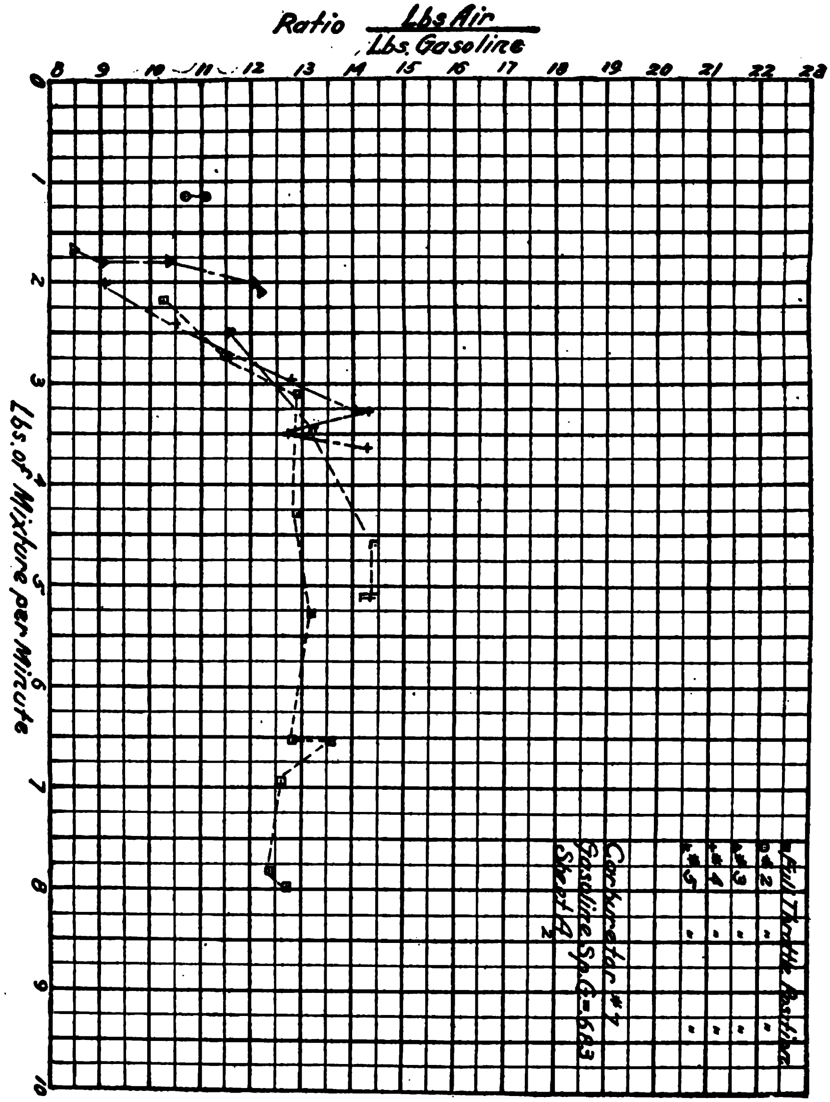
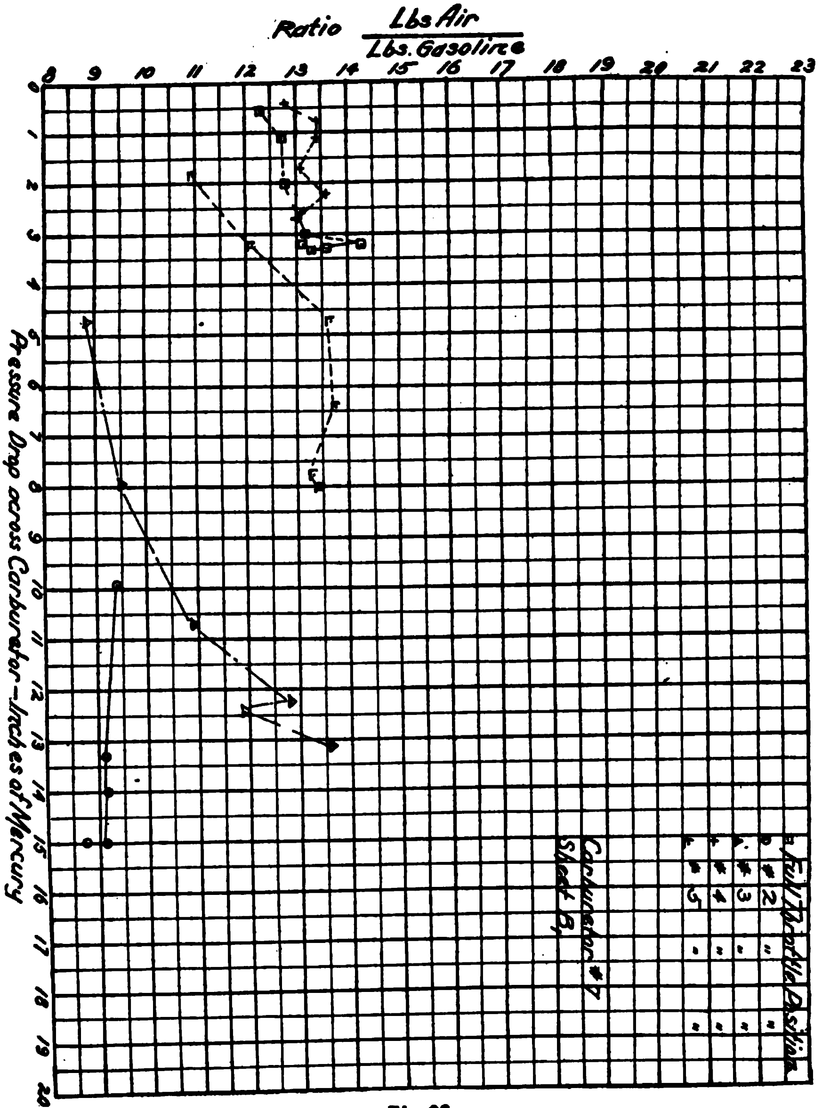

Ratio Lbs Air / Lbs. Gasoline
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
0 1 2 3 4 5 6 7 8 9 10
Lbs. of Mixture per Minute
Full Throttle Position
Carburetor #7
Gasoline Sp. G. = .683
Sheet A2

Fig. 38.



Ratio Lbs Air / Lbs. Gasoline
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Pressure Drop across Carburetor - Inches of Mercury
Carburetor #7
Sheet B.
Full Throttle Position

Fig. 39.

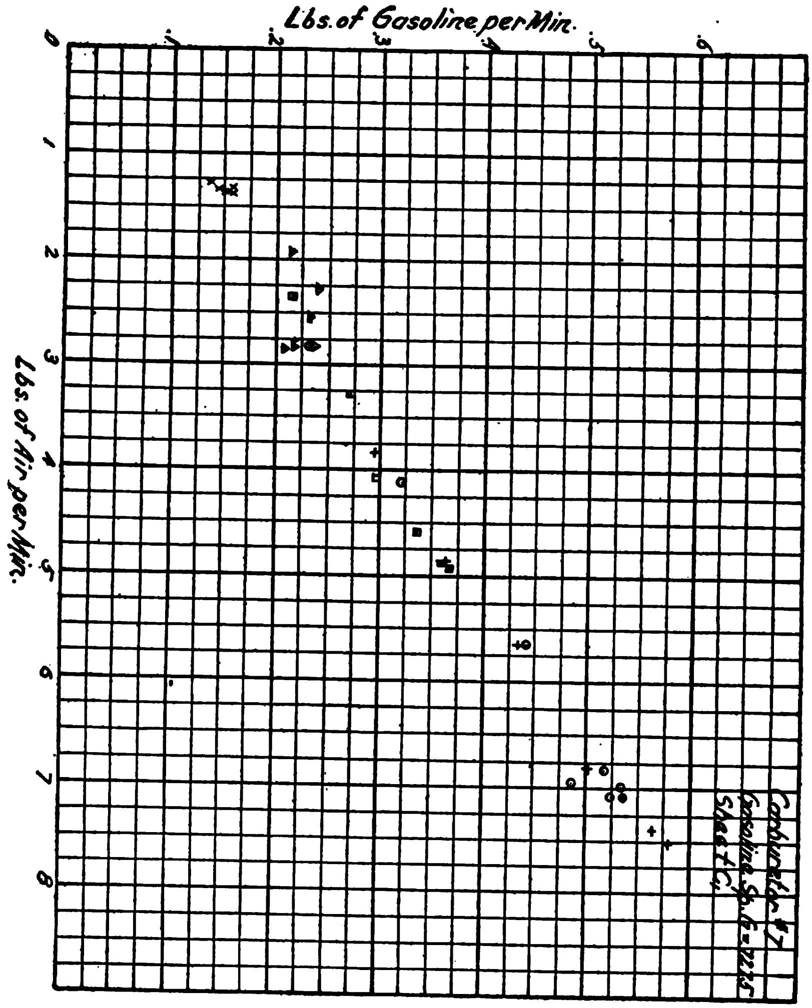


Fig. 40.

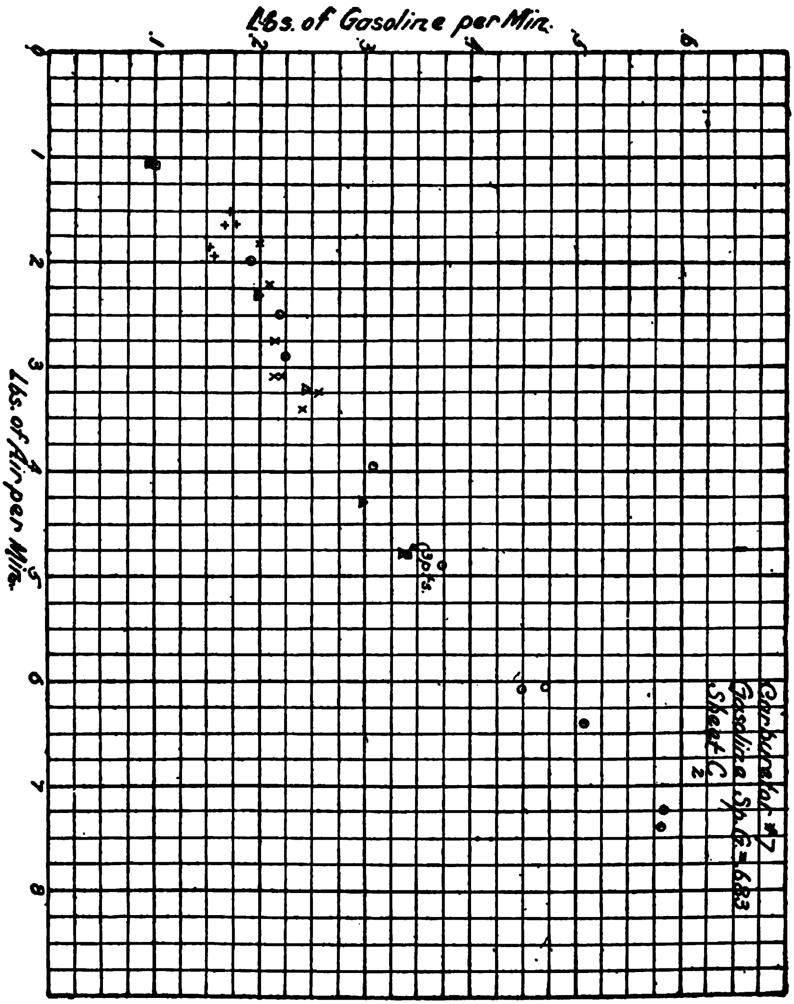

Lbs. of Gasoline per Min.
Lbs. of Air per Min.
Carburetor #7
Gasoline Sp. G. = .683
Sheet C 2/2

Fig. 41.

Carburetor No. 8 (*fig. 42*).—The principal features of this carburetor are a vertical plunger fitting in a cylinder, the upper side of which forms a dash port, air openings being uncovered as the plunger rises, and a tapered fuel metering pin rigidly attached to the hollow plunger, and dipping into the stationary aspirating tube. The plunger is "floating" in the current of air, which results in a practically constant vacuum in the mixing chamber surrounding the plunger. The test results substantiate the manufacturer's claim of a "constant vacuum carburetor." As figure 56 and Table X prove, the greatest difference in suction at the mouth of the fuel nozzle between minimum and maximum flow rates is only 0.8 inch of water. The carburetor belongs in new class 12.7, and the principal difference between it and No. 3 and No. 5 is that in No. 5 the whole metering pin is submerged in the fuel, and in No. 3 the point where the metering pin emerges from the aspirating tube is in the current of air, while in No. 8 the latter point is surrounded by air, but this air is dead air, so to speak, away from the air current, more or less saturated with fuel. The feature, however, which puts this in a class distinct from No. 3 and No. 5 is that the top of the air-tight float chamber is connected by a small tube to the mixing chamber. The vacuum thus produced on top of the fuel, however, may be varied by means of a hand regulated air valve which allows more or less air to leak in, thus partially destroying the vacuum and regulating the fuel flow. By means of an adjustable collar supporting the plunger when at rest, the opening of the fuel ports is given a "lead" with respect to the air ports which results in a richer mixture for idling.

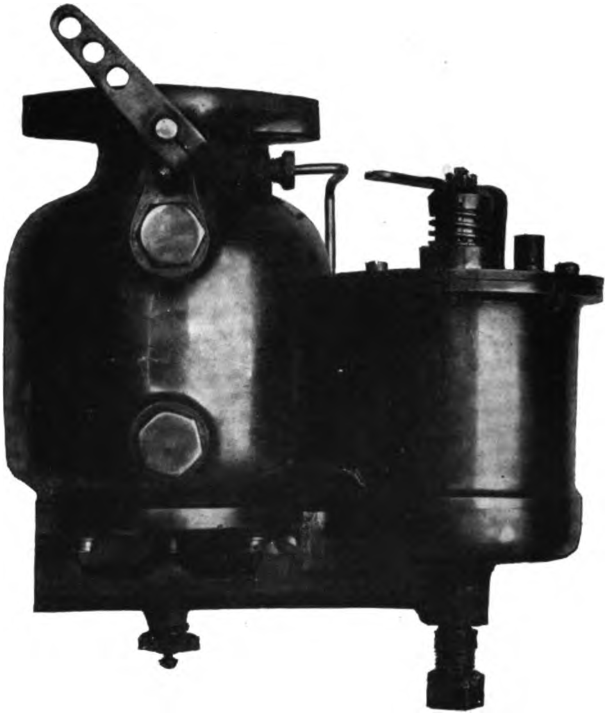
Discussion of results (see figs. 43, 44, 45):

(*a*) The effect of the idling arrangement above described is plainly seen in figure 43 where the points of group 2 represent the idling position.

(*b*) Figures 43 and 45 show that the mixture gradually becomes leaner as the flow increases, up to about 8 pounds per minute mixture flow. At this point apparently the plunger has reached the limit of its travel, and the carburetor becomes a fixed air-inlet fixed fuel-inlet carburetor which accounts for the mixture becoming richer. Eight pounds represents, therefore, the limit of the working range unless a richer mixture is desired at extreme engine speeds in order to obtain maximum power for racing or whenever maximum engine power is desired.

(*c*) Between 2 and 8 pounds per minute mixture flow, the air-fuel ratio increases from 12 to 16, an increase of 33 per cent, or a variation of 28.6 per cent referred to a mean ratio of 14. This general tendency can, in the case of this carburetor, be changed only by substituting a metering pin of different contours.

(*d*) If one were to omit about six erratic readings, the results would be very good, even excellent, as far as constancy of proportions for any one rate of flow at different throttle positions is concerned. What right anyone has, however, to omit inconvenient readings is not evident, as long as no experimental error can be shown. Again occasional binding of the plunger is the only plausible explanation. The special test plotted in figure 56 does not give any indication of irregularities in the plunger action, but that can not be considered as conclusive unless a great many readings were taken.



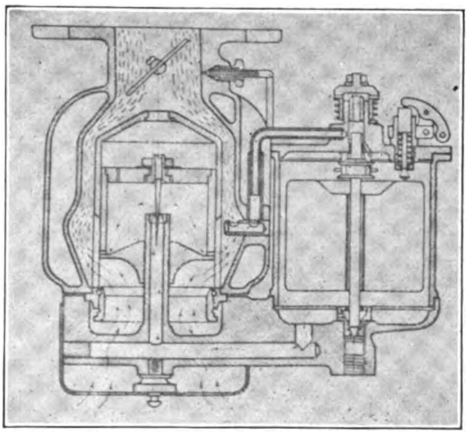


FIG. 42.—Carburetor No. 8.

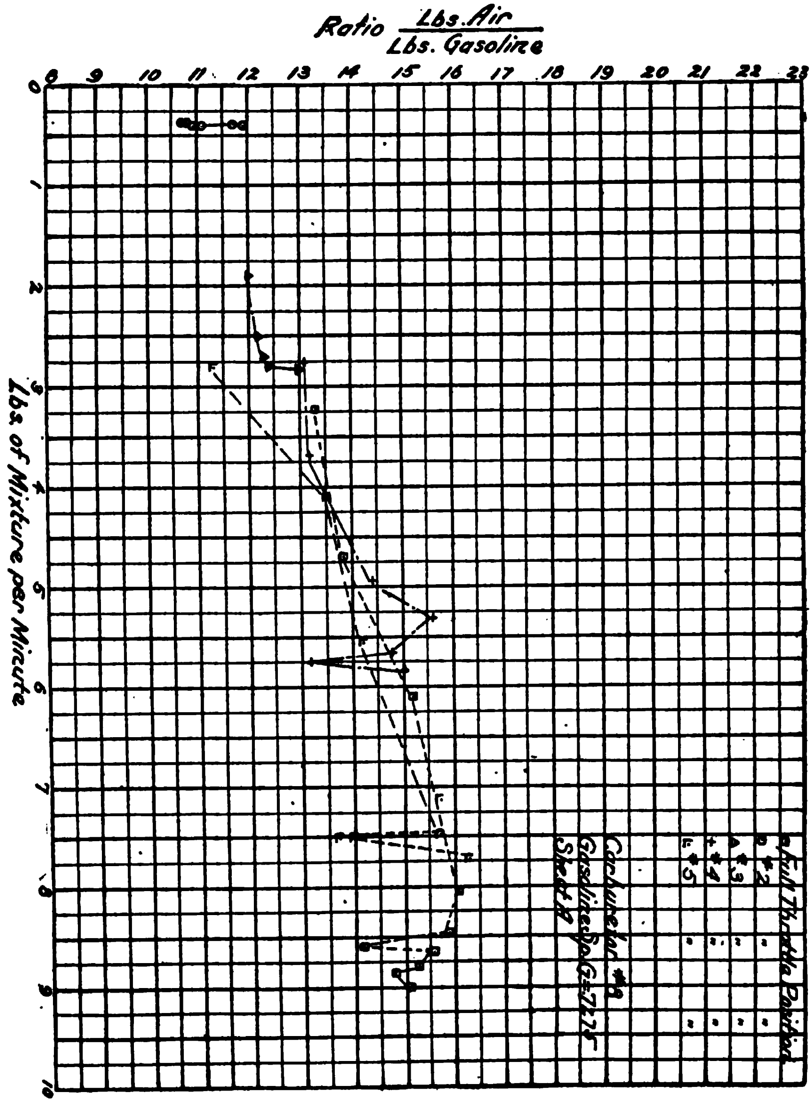

Ratio Lbs. Air / Lbs. Gasoline
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Lbs. of Mixture per Minute
0 1 2 3 4 5 6 7 8 9 10
Full Throttle Position
#2
#3
#4
#5
Carburetor #9
Gasoline Sp. G. = .725
Sheet A

Fig. 43.

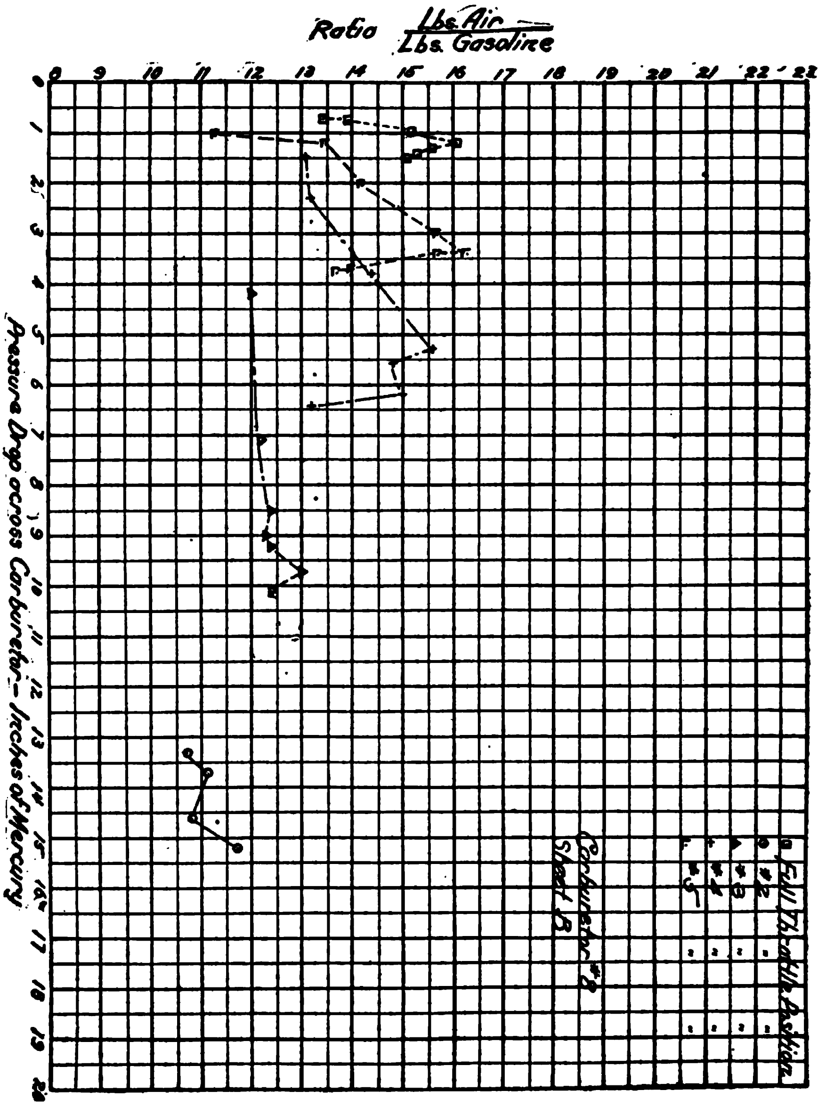

Ratio Lbs. Air / Lbs. Gasoline
Pressure Drop across Carburetor – Inches of Mercury
Carburetor #2
Sheet B
Full Throttle Position
#2
#3
#4
#5

Fig. 44.

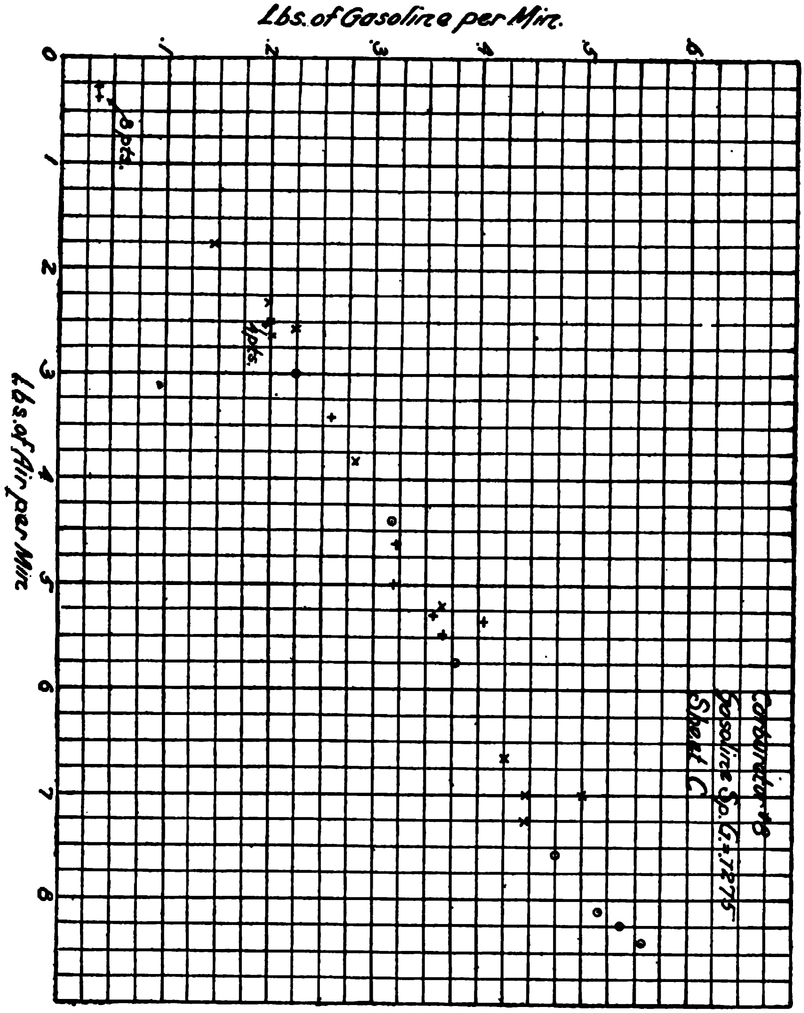

Lbs. of Gasoline per Min.
Lbs. of Air per Min.
Carburetor #8
Gasoline Sp. G. = .7275
Sheet C
8 pts.
4 pts.
0
.1
.2
.3
.4
.5
.6
1
2
3
4
5
6
7
8

Fig. 45.

(e) Since this is a carburetor in which the deflection of the current, due to the throttle position, can not possibly have any effect on the fuel flow (see fig. 42), and since the great differences in some of the other carburetors can only be due to the deflection by the throttle, the fact that the ratios for different throttle positions at the same flow rate agree quite closely, assumes considerable significance, but further investigations are required before this question can be conclusively settled.

(f) The variations in float chamber level were practically nil.

Carburetor No. 9 (fig. 46).—This carburetor has a small fixed area Venturi tube for the air inlet with a fixed area fuel spray nozzle, the flow through which may be adjusted by hand by means of a submerged needle valve. In addition it has a fixed area spray nozzle located under the hinged flap of a spring loaded auxiliary air valve. The secondary nozzle, therefore, does not act until there is sufficient suction to open the auxiliary air valve. This arrangement places the carburetor in new class 10.9.

Discussion of test results (see figs. 47, 48, and 49).

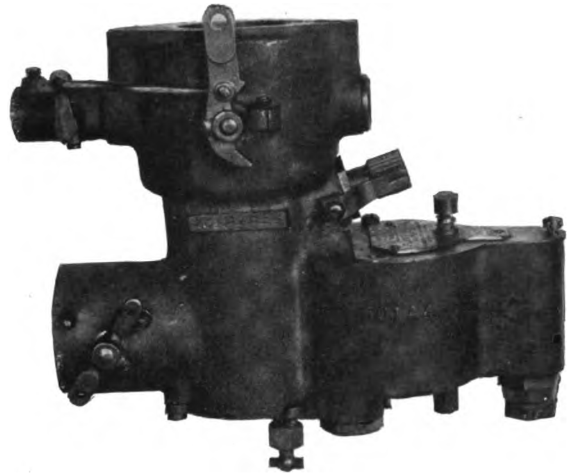
(a) The prints of group 2 (fig. 47) represent the idling position of the throttle, and again—the same as in other carburetors—a great variation in the mixture proportions is to be found. The air-gasoline ratio increases from 7.6 to 12.1.

(b) In the other throttle positions a distinct break occurs at a flow rate of about 2 pounds per minute. It must be concluded that this represents the point at which the auxiliary air valve and the secondary jet begin to affect the mixture.

(c) The air-gasoline ratio steadily increases at a uniform rate from about 10.5 at 2 pounds flow (fig. 47) to 16.6 at nearly 8 pounds flow, but between 1.7 pounds and 2.1 pounds it increases from 8.6 to 10.5, an increase of 22 per cent for an increase in flow of 23.5 per cent, while between 2 and 8 pounds, the ratio increases 58 per cent for an increase in flow of 400 per cent. A change in spring tension should enable the operator to reduce this excessive increase in the ratio, but the location of the secondary nozzle under the tip of the flap valve and close to the wall produced very curious and erratic results when the attempt was made to correct the adjustment. Lack of time prevented further investigation, but there is no doubt that the carburetor as furnished could not be adjusted to give a constant mixture at different flow rates, even for a single throttle position. What effects the substitution of another spring or of another secondary nozzle or the shifting of the point of the latter by bending the tube might produce, would be idle to discuss on the basis of theoretical considerations only.

(d) With the exception of only two or three readings the carburetor showed no irregular tendencies, and the ratio vs. flow curves (fig. 47) are fairly smooth, indicating that the auxiliary valve, the only moving part, worked freely.

(e) Regarding constancy of proportions for any one flow rate when passing from one throttle position to another, it may be noted that at 2 pounds per minute flow the ratios agree within 4 per cent of the mean, at 4.5 pounds within about 7 per cent, and at 7.5 pounds within less than 4 per cent of the mean ratio. These differences are



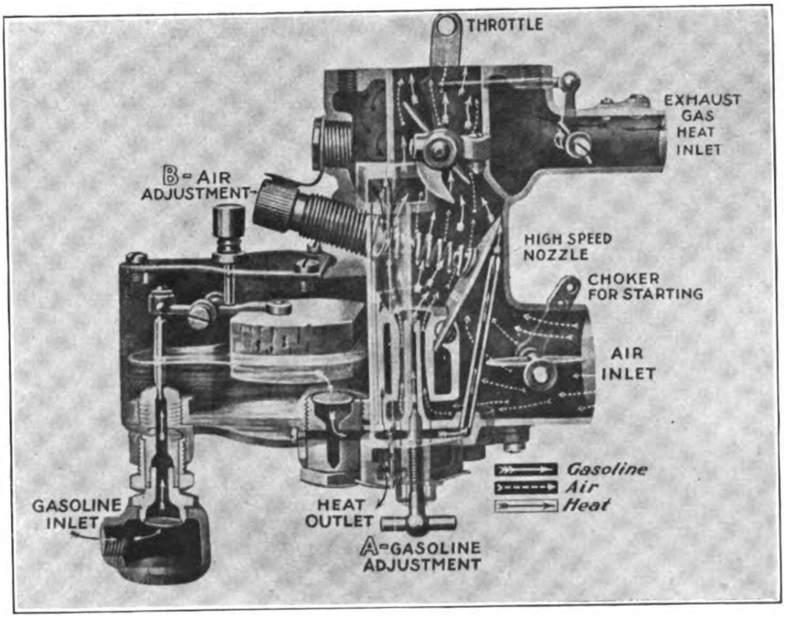


FIG. 46.—Carburetor No. 9.

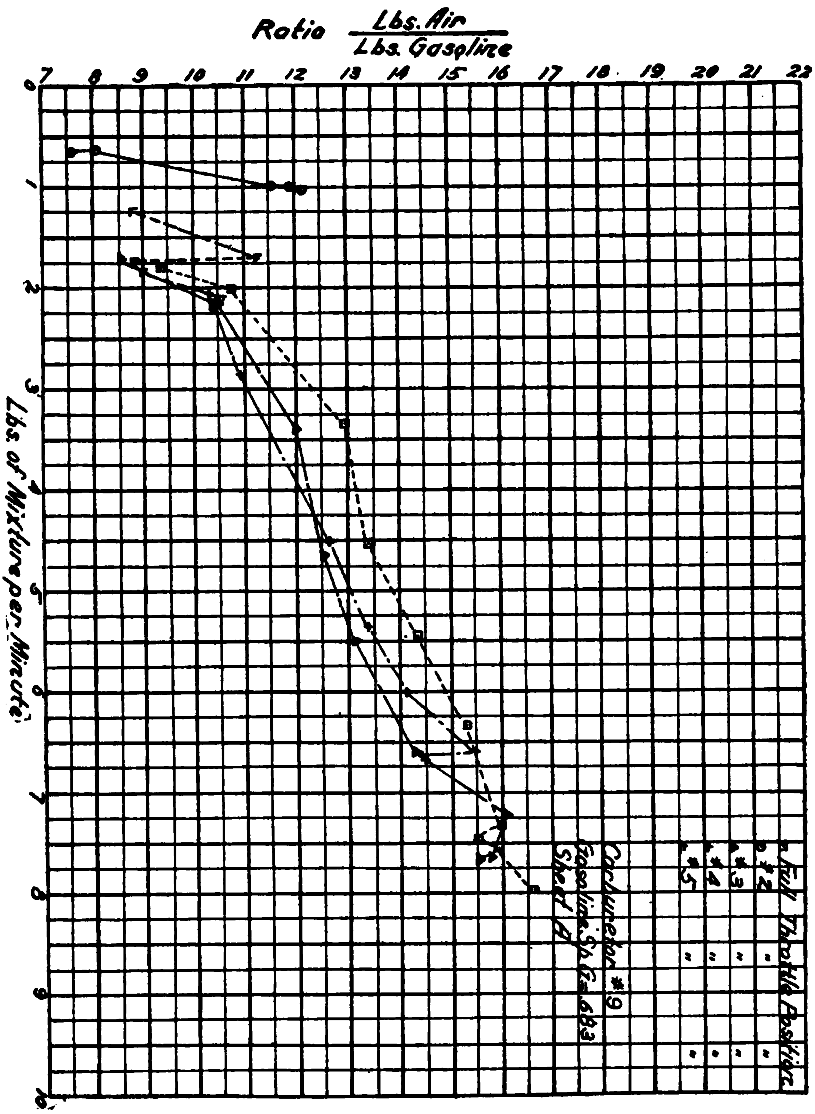

Ratio Lbs. Air / Lbs. Gasoline
7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
0 1 2 3 4 5 6 7 8 9 10
Lbs. of Mixture per Minute.
Carburetor #9
Gasoline Sp. G. = .683
Sheet A
Full Throttle Position
#2
#3
#4
#5

Fig. 47.

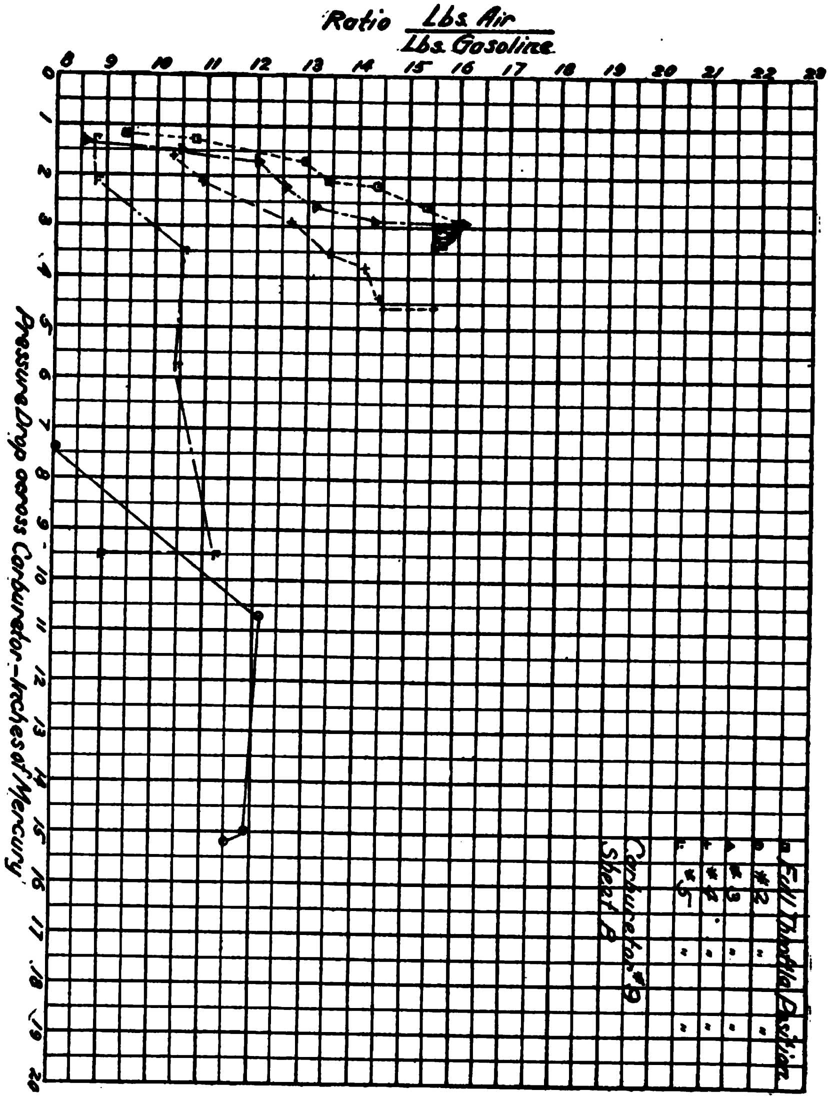

Ratio Lbs. Air / Lbs. Gasoline
Pressure Drop across Carburetor - Inches of Mercury
Full Throttle Position
Carburetor #9
Sheet B

Fig. 48.

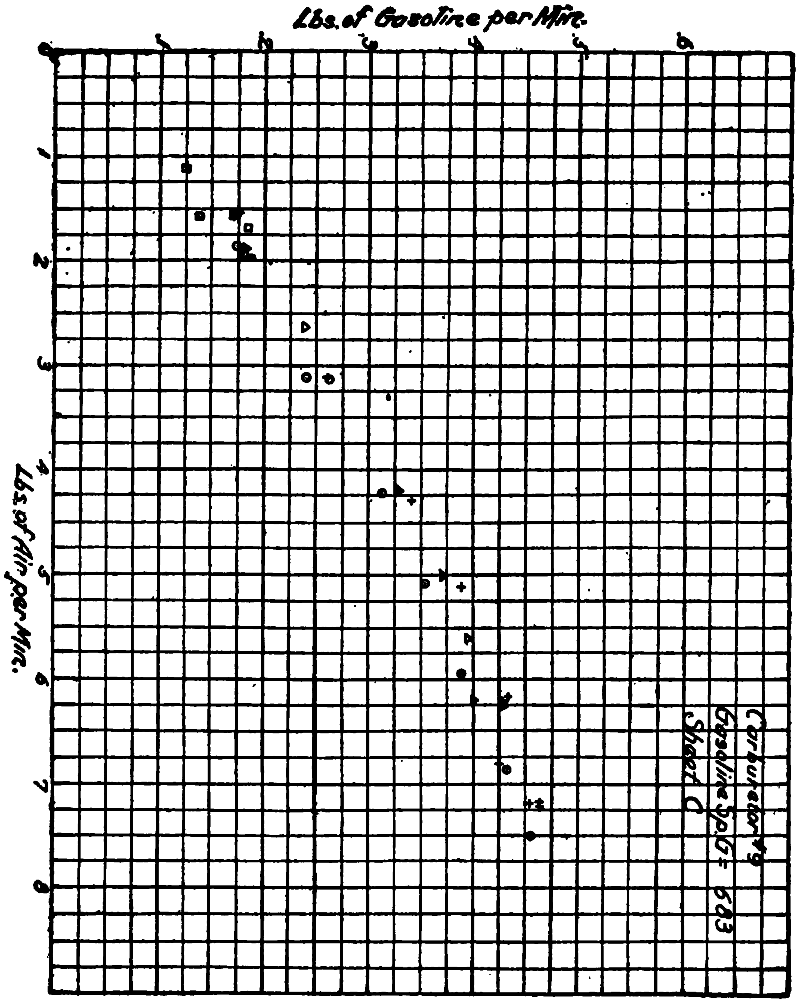

Lbs. of Gasoline per Min.
Lbs. of Air per Min.
Carburetor #9
Gasoline Sp. G. = 683
Sheet C

Fig. 49.

to be ascribed to the disturbing action of the throttle which must be quite pronounced in the case of this carburetor. (See cross section in fig. 46.)

(*f*) No variation in the float-chamber level could be observed.

Carburetor No. 10 (*fig. 50*).—In this carburetor the fuel issues from a number of very small holes, and a cylindrical rotary throttle with suitably shaped ports uncovers the fuel openings one by one, so the carbureter may be said to consist of a number of carburetors, each with a fixed air inlet and a fixed fuel inlet. Thus it comes under new class 9.2. An adjustable damper plate in the air passage provides hand regulation of the mixture.

Discussion of results (see figs. 51, 52, and 53): From the construction of the carburetor one would expect to find on sheet A (fig. 51) five quite similar curves, sloping gradually, even if slightly only, downward as the flow increases. The actual results as shown are disappointing as well as puzzling. Beginning with a closed throttle, the first position is represented by No. 2, the next by No. 3, and then No. 4, No. 5, and full throttle follow in the order given. Leaving aside positions No. 2 and No. 3 which represent very small flow rates only, and which show enormous variations in ratios, between 13 and 23 in one case and between 15.5 and 18.3 in the other, as was expected from the experience with the other carburetors, it might be possible to draw curves representing mean values, and these curves would be approximately parallel, and slightly sloping downward, but the fluctuations are so large, with the exception of group No. 5, that it seems idle to speak of general tendencies in mixture variation. It is especially striking that even the full throttle test which usually furnishes the most regular curves, in this case gives very erratic results, with successive ratio readings of 19.1, 16.5, 19.4, 18.2, 15.8, 15.9, 15.9, 15.6. Of course if the 19.4 and the 18.2 readings at 4.3 and 5.1 pounds, respectively were lowered to about 16, the results would at once show a most radical improvement, but there is no justification for any such procedure. A satisfactory explanation for the erratic readings given by this carburetor does not suggest itself.

The depression of far float chamber level was 0.2 at the higher flow rates, not sufficient to affect the flow appreciably.

Special tests.—After the completion of the regular tests, each carburetor was subjected to a special test the object of which was to ascertain the vacuum at the outlet of the spray nozzle for the whole range of flow rates. For this purpose the connection between the spray nozzle and the float chamber was plugged with plaster of Paris and the same was done with any outlets to auxiliary wells, etc., so that a manometer connected to the gasoline passage leading to the spray nozzle would read the actual pressure at the mouth, i. e., the vacuum which, with the float chamber head at the other end of the fuel column, determines the flow. The throttle was kept open full for these tests and air was passed through the carburetor and metered the same as during the regular tests.

The log of these tests appears on Tables IX and X and curves plotted from these readings, on figures 54–56.

These results, together with the readings of the regular tests, may be used for deducing an empirical formula for the flow in each car-

buretor, or for trying such formulæ as have been proposed for this purpose providing that the exact flow area for each flow rate is determined which is not an easy matter especially for the fuel passage, and where metering pins are used. The air flow, however, can not be calculated from these readings, since in general they do not represent the true static pressure of the air, and of course when air enters through auxiliary valves, even the true pressure at the primary nozzle would not be of any use by itself.

TABLE IX–X.—*Log of carburetor tests, Columbia University, June to August, 1916.*

CARBURETOR NO. 1.

[Aug. 2, 1916; average barometer, 30.17 inches.]

Run No.	Venturi meter. Size, inches.	Venturi meter. Left.	Venturi meter. Right.	Venturi meter. Height, inches water.	Pressure at Venturi inlet, inches water.	Pounds air per minute.	Suction at mouth of fuel nozzle, inches water.	Pressure in box.	Temperature at carburetor inlet.	Revolutions per minute.
1	¾	4.7	1.6	6.3	1.4	2.30	15.3	0	87	210
2	¾	8.5	5.5	14.0	3.1	3.35	21.0	0	86	310
3	¾	11.3	9.2	19.5	4.1	3.90	24.2	0	86	400
4	¾	17.7	15.1	32.3	6.2	4.92	31.2	0	86	500
5	1	6.0	6.2	12.2	2.0	5.60	36.6	0	86	600
6	1	8.0	8.2	16.2	2.6	6.30	41.0	0	88	700
7	1	10.2	10.8	21.0	3.6	7.20	42.2	0	89	800
8	1	11.2	12.2	23.2	3.6	7.54	43.5	0	89	900
9	1	12.0	13.0	25.0	4.2	7.80	44.8	0	90	1,000
10	1	12.2	13.2	25.4	4.3	7.80	46.2	0	90	1,200
11	1	12.2	13.2	25.4	4.3	7.80	41.5	0	91	1,440

CARBURETOR NO. 2.

Run No.	Size, inches.	Left.	Right.	Height, inches water.	Pressure at Venturi inlet, inches water.	Pounds air per minute.	Suction at mouth of fuel nozzle, inches water.	Pressure in box.	Temperature at carburetor inlet.	Revolutions per minute.
12	¾	4.2	1.0	5.2	1.2	2.10	11.3	0	86	180
13	¾	5.3	2.2	7.5	1.4	2.50	14.0	0	86	250
14	¾	8.7	5.8	14.5	2.7	3.43	17.1	0	86	330
15	¾	10.5	7.5	18.0	3.8	3.80	18.4	0	86	400
16	¾	18.0	15.5	33.5	6.5	5.00	22.8	0	86	500
17	1	6.2	6.3	12.5	2.0	5.65	26.2	0	86	600
18	1	8.2	8.6	16.8	2.8	6.45	29.0	0	87	700
19	1	10.2	11.0	21.2	3.8	7.20	31.1	0	88.5	840
20	1	11.5	12.4	23.9	3.6	7.62	33.1	0	89.0	990
21	1	11.8	12.7	24.5	3.7	7.70	34.0	0	89.5	1,140
22	1	11.8	12.7	24.5	3.7	7.70	34.0	0	89.5	1,440

CARBURETOR NO. 3.

[July 27, 1916; average barometer, 29.86 inches.]

Run No.	Size, inches.	Left.	Right.	Height, inches water.	Pressure at Venturi inlet, inches water.	Pounds air per minute.	Suction at mouth of fuel nozzle, inches water.	Pressure in box.	Temperature at carburetor inlet.	Revolutions per minute.
23	¾	4.5	1.8	6.3	1.8	2.30	7.3	0	82	230
24	¾	7.6	5.0	12.6	2.6	3.19	11.6	0	82	330
25	¾	15.7	13.2	28.9	5.4	4.67	9.2	0	82	480
26	¾	22.8	21.2	44.0	8.6	5.62	11.4	0	82	600
27	1	9.2	10.2	19.4	3.0	6.98	14.0	0	82	720
28	1	12.4	14.0	26.4	4.5	8.00	13.4	0	82	860
29	1	10.0	11.0	21.0	3.5	7.20	14.7	0	82	750
30	1	14.2	16.3	30.5	5.0	8.50	14.7	0	82	980
31	1	15.2	17.3	32.5	5.4	8.82	15.8	0	82	1,080
32	1	15.6	17.8	33.4	5.4	8.92	16.1	0	82	1,220
33	1	15.5	17.7	33.2	5.5	8.90	16.1	0	82	1,350

TABLE IX-X.—*Log of carburetor tests, Columbia University, June to August, 1916*—Continued.

CARBURETOR NO. 4.

[Aug. 1, 1916; average barometer, 29.96 inches.]

Run No.	Venturi meter.				Pressure at Venturi inlet, inches water.	Pounds air per minute.	Suction at mouth of fuel nozzle, inches water.	Pressure in box.	Temperature at carburetor inlet.	Revolutions per minute.
	Size, inches.	Left.	Right.	Height, inches water.						
34	[illegible]	4.5	1.5	6.0	1.4	2.23	5.3	0	85	200
35	[illegible]	7.0	4.0	11.0	2.3	2.96	9.7	0	86	295
36	[illegible]	12.3	9.6	21.9	4.3	4.12	20.5	0	86	430
37	[illegible]	17.8	15.2	33.0	6.2	4.92	29.1	0	86	520
38	[illegible]	23.5	21.5	45.0	8.8	5.60	41.8	0	86	630
39	1	9.0	9.6	18.6	3.1	6.80	50.3	0	86	770
40	1	10.2	11.0	21.2	3.2	7.20	54.4	0	86	850
41	1	11.7	12.7	24.4	4.0	7.70	59.8	0	86	980
42	1	11.6	12.8	24.4	4.0	7.70	62.5	0	86	1,140
43	1	12.2	13.3	25.5	4.2	7.80	60.3	0	86	1,480

CARBURETOR NO. 5.

[Aug. 2, 1916; average barometer, 30.17 inches.]

44	[illegible]	4.3	1.1	5.4	1.2	2.15	14.7	0	85	200
45	[illegible]	7.0	3.9	10.9	2.3	2.98	12.5	0	85	300
46	[illegible]	9.8	6.8	16.6	3.3	3.65	13.5	0	85	400
47	[illegible]	16.8	14.0	30.8	5.0	4.82	13.0	0	85	500
48	1	6.0	6.0	12.0	2.3	5.53	13.5	0	85	600
49	1	8.3	8.6	16.9	2.8	6.62	14.5	0	87	700
50	1	10.5	11.3	21.8	3.3	7.33	15.6	0	87	800
51	1	12.1	13.0	25.1	4.1	7.80	15.9	0	88	900
52	1	13.2	14.3	27.5	4.3	8.10	16.2	0	89	1,000
53	1	13.6	14.6	28.1	4.4	8.18	17.5	0	89	1,152
54	1	14.0	15.1	29.1	4.8	8.30	18.5	0	89	1,440

CARBURETOR NO. 6.

[Aug. 3, 1916; average barometer, 29.94 inches.]

							Aux.	*Main.*			
55	[illegible]	5.0	1.8	6.8	1.8	2.28	0.4	3.8	0	82	200
56	[illegible]	7.1	3.8	10.9	2.4	3.00	0.7	4.5	0	82	300
57	[illegible]	14.6	11.6	26.2	5.1	4.48	1.1	6.5	0	82	420
58	[illegible]	16.6	13.8	30.4	6.0	4.78	1.5	6.6	0	82	500
59	1	8.1	8.3	16.4	3.0	6.47	2.2	8.4	0	82	650
60	1	11.0	11.6	22.6	3.6	7.40	3.0	10.4	0	82	800
61	1	12.8	13.6	26.4	4.2	8.00	3.1	10.9	0	82	950
62	1	13.2	14.3	27.5	4.6	8.10	3.2	11.4	0	82	1,100
63	1	13.9	14.8	28.7	4.6	8.26	3.2	11.4	0	83	1,400

CARBURETOR NO. 7.

[July 27, 1916; average barometer, 29.86 inches.]

64	[illegible]	14.8	14.6	29.4	7.2	1.53	4.08	0	82	225
65	[illegible]	9.0	6.3	15.3	3.0	3.52	10.86	0	82	350
66	[illegible]	18.3	16.3	34.6	6.6	5.07	19.08	0	82	550
67	[illegible]	12.4	9.8	22.2	4.3	4.20	13.60	0	82	440
68	1	7.0	7.7	14.7	2.3	6.10	24.45	0	82	660
69	1	9.2	10.3	19.6	3.0	7.00	31.25	0	82	770
70	1	11.0	12.3	23.3	3.6	7.60	38.10	0	82	900
71	1	12.0	13.5	25.5	4.3	7.95	42.20	0	82	1,010
72	1	12.1	13.6	25.7	4.2	7.95	42.20	0	82	1,120
73	1	12.5	14.0	26.5	4.4	8.10	43.60	0	82	1,200
74	1	12.2	13.7	25.9	4.3	7.97	43.60	0	82	1,240
75	1	12.3	13.8	26.1	4.2	7.97	42.20	0	82	1,400

TABLE IX-X.—*Log of carburetor tests, Columbia University, June to August, 1916*—Continued.

CARBURETOR NO. 8.

[Aug. 3, 1916; average barometer, 29.94 inches.]

Run No.	Venturi meter.				Pressure at Venturi inlet, inches water.	Pounds air per minute.	Suction at mouth of fuel nozzle, inches water.	Pressure in box.	Temperature at carburetor inlet.	Revolutions per minute.
	Size, inches.	Left.	Right.	Height, inches water.						
76	[illegible]	4.6	1.6	6.2	1.3	2.27	7.3	0	85	200
77	[illegible]	8.2	5.0	13.2	2.8	3.25	7.3	0	85	310
78	[illegible]	14.2	11.5	25.7	5.4	4.45	7.4	0	85	450
79	[illegible]	20.1	17.9	38.0	7.0	5.30	7.5	0	85	550
80	1	7.1	7.3	14.4	2.4	6.05	7.9	0	86	800
81	1	8.5	9.0	17.5	2.8	6.60	8.0	0	86	900
82	1	9.0	9.5	18.5	3.0	6.80	8.0	0	87	1,040
83	1	8.5	9.0	17.5	2.9	6.60	8.1	0	87	1,200
84	1	9.7	9.7	18.9	3.0	6.90	8.1	0	87	1,050
85	1	9.0	9.4	18.4	3.0	6.80	8.1	0	88	1,460
86	1	9.0	2.5	18.5	3.0	6.80	8.0	0	88	....

CARBURETOR NO. 9.

Run No.	Size, inches.	Left.	Right.	Height, inches water.	Pressure at Venturi inlet, inches water.	Pounds air per minute.	Suction at mouth of fuel nozzle, inches water.	Pressure in box.	Temperature at carburetor inlet.	Revolutions per minute.
87	[illegible]	4.7	1.5	6.2	1.4	2.27	4.7	0	83	200
88	[illegible]	7.2	4.0	11.2	2.5	3.00	7.3	0	84	300
89	[illegible]	14.2	11.1	25.3	5.0	4.41	12.1	0	84	470
90	[illegible]	20.2	17.7	37.8	7.0	5.28	15.5	0	84	600
91	1	8.0	8.2	16.2	2.6	6.40	19.0	0	85	700
92	1	10.0	10.5	20.9	3.4	7.12	21.5	0	85	820
93	1	10.7	11.3	22.0	3.6	7.35	23.2	0	86	900
94	1	12.0	12.8	24.8	4.2	7.80	23.8	0	86	1,040
95	1	12.0	13.0	25.0	4.5	7.82	24.0	0	86	1,160
96	1	12.1	13.1	25.2	4.5	7.85	24.3	0	87	1,440

CARBURETOR NO. 10.

Run No.	Size, inches.	Left.	Right.	Height, inches water.	Pressure at Venturi inlet, inches water.	Pounds air per minute.	Suction at mouth of fuel nozzle, inches water.	Pressure in box.	Temperature at carburetor inlet.	Revolutions per minute.
97	[illegible]	5.1	1.9	7.0	1.7	2.42	1.2	0	82	210
98	[illegible]	7.7	4.5	12.2	2.6	2.13	3.4	0	82	300
99	[illegible]	15.5	12.5	28.0	5.4	4.65	5.7	0	82	460
100	[illegible]	22.5	20.5	46.0	8.4	5.72	8.0	0	83	580
101	1	8.5	8.7	17.2	3.0	6.60	11.0	0	83	680
102	1	11.1	11.6	22.7	3.5	7.50	14.8	0	84	800
103	1	12.8	13.8	26.6	4.5	8.00	16.6	0	85	900
104	1	14.0	15.0	29.0	4.8	8.30	18.2	0	85	1,020
105	1	14.1	15.1	29.2	4.8	8.32	18.6	0	85	1,150
106	1	14.1	15.1	29.2	4.7	8.32	18.6	0	85	1,440

As has been repeatedly pointed out in the discussion of the individual tests, in some cases the irregularities in the variation of the mixture ratio with flow is explained by the irregularity of the corresponding pressure readings, which in turn are due to sticking or binding of moving parts.

In carburetors Nos. 4 and 5 (see fig. 54) the curves also plainly show the points where the compensating arrangement ceases to be effective.

Carburetors Nos. 5 and 8 are intended to be "constant vacuum" instruments, and the curves on figures 54 and 56 confirm it.

No. 3 is also a constant vacuum carburetor, but the spray nozzle is directly at the point where the throttling takes place; therefore the curve figure 55 shows a gradually increasing suction with a maximum of 3 inches of water.

Carburetors Nos. 1, 2, 6, and 9 have spring-loaded auxiliary air valves and should therefore show similar relations between mixing chamber vacuum and air flow. The curves show that all four have this relation expressed by a straight linge of the equation $y=ax+b$, where y=vacuum, x=air flow, and a and b are constants. Naturally, if the curves could have been continued to the left, they would have curved off toward the origin, but the straight-line relation holds true for all except the lowest flow rates.

In the case of No. 6 carburetor separate tests were made for the primary and secondary nozzle pressures, and the two curves show plainly how the suction at the primary nozzle gives the same results as Nos. 1 and 2, but suction at the secondary nozzle begins to develop only when the flow amounts to about 2 pounds per minute; after that suction increases along a straight line. In the test of No. 9 carburetor the two nozzles were not separated. This explains why the curve is a straight line, but follows the equation $y=ax-b$, i. e., it intersects the zero pressure axis to the right of the origin.

No. 7 (fig. 55) also should give the same characteristics, since in place of the springs it has the constant weight balls. The curve shows a straight line only up to about 4 pounds. After that the suction increases more rapidly. This is probably due to the fact that in this case the pressure read on the manometer is the pressure at the throat of the Venturi tube rather than that of the mixing chamber.

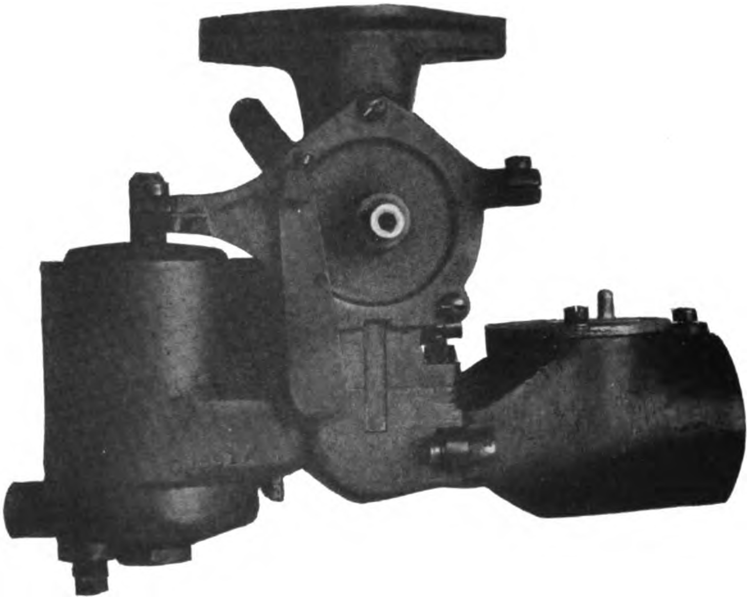
The two remaining carburetors, Nos. 4 and 10, should, under the test conditions, give the characteristic curves of a carburetor with fixed air inlet and fixed fuel inlet. The actual results are as expected, only the curve for No. 10 (fig. 56) is improperly plotted as a straight line. Actually it is a curve similar to that of No. 4 (fig. 54), as inspection will show.

The great difference in the practice of the various manufacturers with respect to suction at the spray nozzle deserves mention. Assume an air flow of 7 pounds per minute, a flow rate which is certainly well within the working range of all the instruments. At this flow rate the constant vacuum carburetors have vacua of 2, 8, and 15 inches of water, respectively, while the others show 9, 12, 21, 30, 32, 40, and 54 inches of water, respectively.

SUMMARY OF TEST RESULTS.

(1) The tests performed in connection with this investigation, as has been explained before, were intended only to demonstrate the performance of modern commercial carburetors as metering or proportioning instruments. But even with this narrow limitation they are not complete; they show how the mixture proportions are affected by speed at fixed throttle and also by throttle position when the engine is running at perfectly uniform speed. They do not show the effects of a sudden change in the flow rate or of a change in barometric pressure or atmospheric temperature. Time, unfortunately, was not available for these extra tests nor for tests showing the effects of the tilting of the carburetor.

(2) While the method adopted for testing was that of varying the speed and flow rate at each of a series of fixed throttle positions



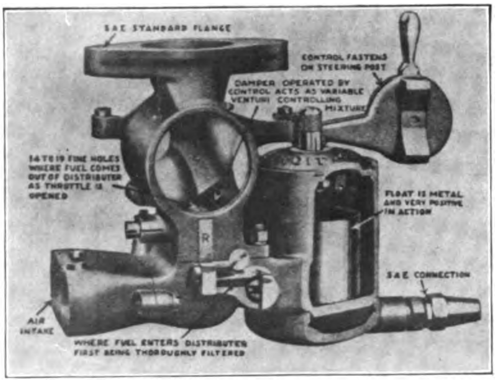


FIG. 50.—Carburetor No. 10

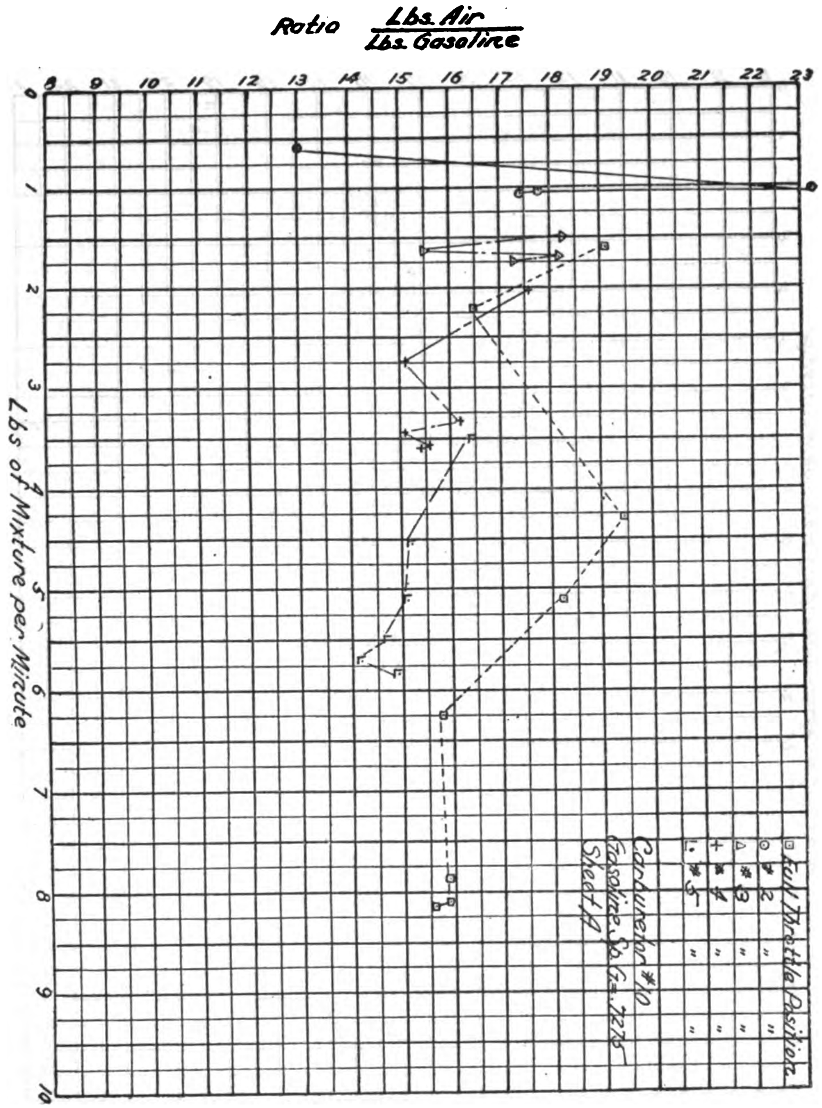

Ratio Lbs. Air / Lbs. Gasoline
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
0 1 2 3 4 5 6 7 8 9 10
Lbs of Mixture per Minute
□ Full Throttle Position
⊙ # 2 " "
△ # 3 " "
+ # 4 " "
⊡ # 5 " "
Carburetor #10
Gasoline Sp. G. = .7275
Sheet A

Fig. 51.

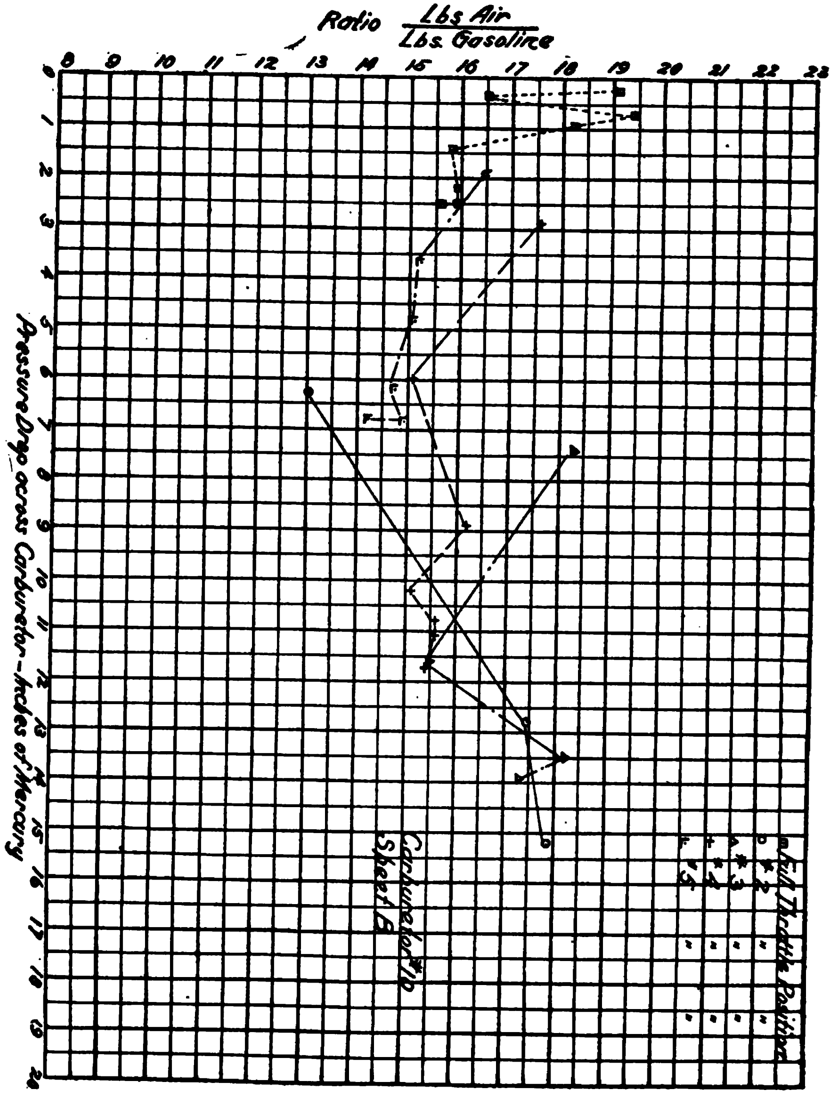

Ratio Lbs Air / Lbs. Gasoline
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Pressure Drop across Carburetor - Inches of Mercury
Carburetor No. 10 Sheet B
Full Throttle Position

Fig. 52.

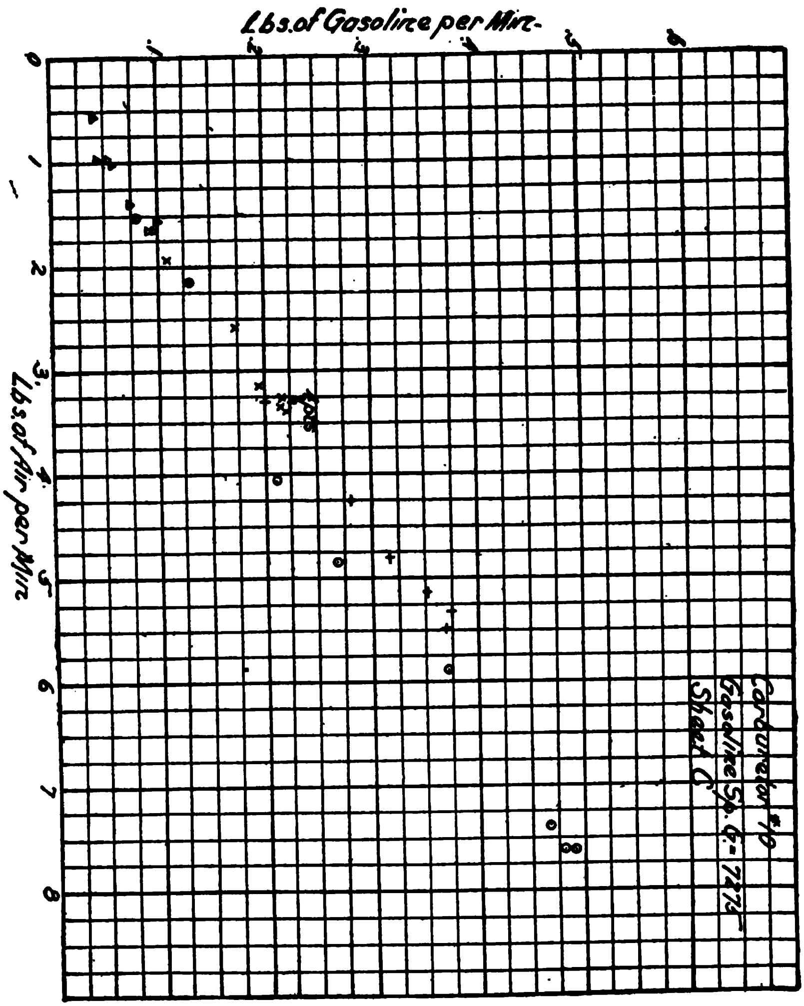

Lbs. of Gasoline per Min.
Lbs. of Air per Min
Carburetor #10
Gasoline Sp. G. .7273
Sheet C

Fig. 63.

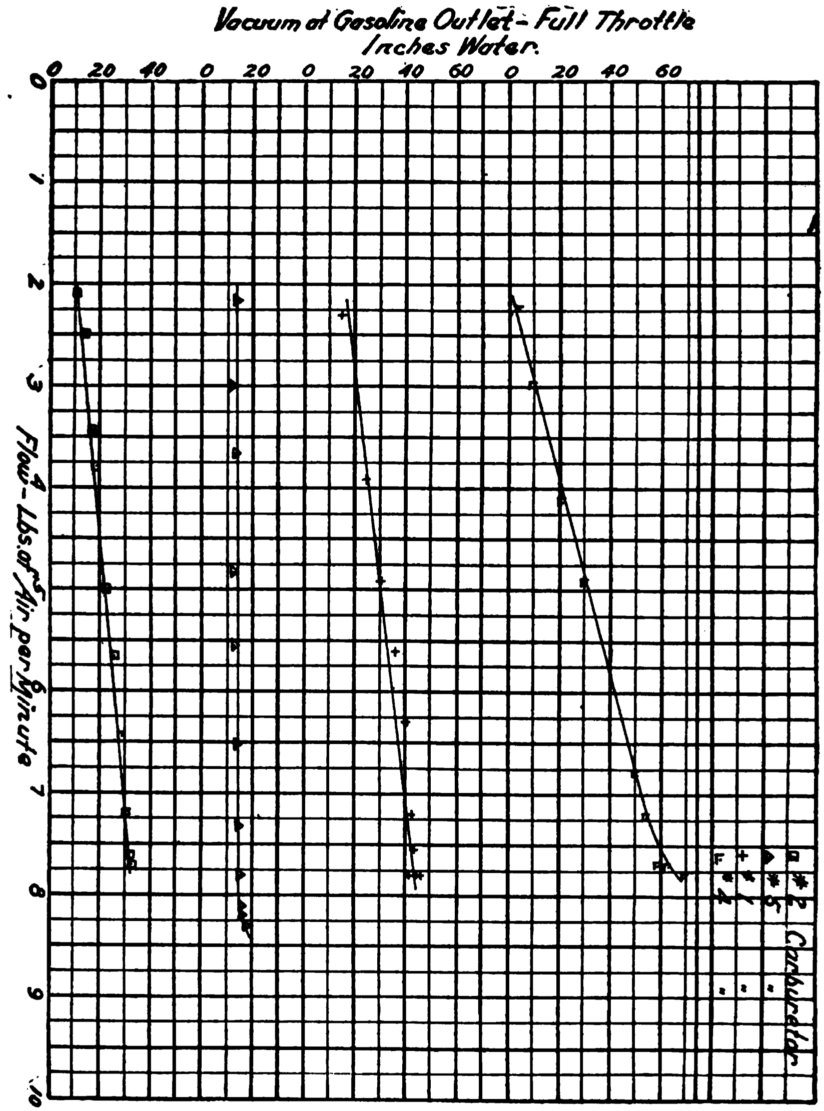

Vacuum at Gasoline Outlet - Full Throttle
Inches Water.
Flow - Lbs. of Air per Minute
Carburetor

Fig. 54.

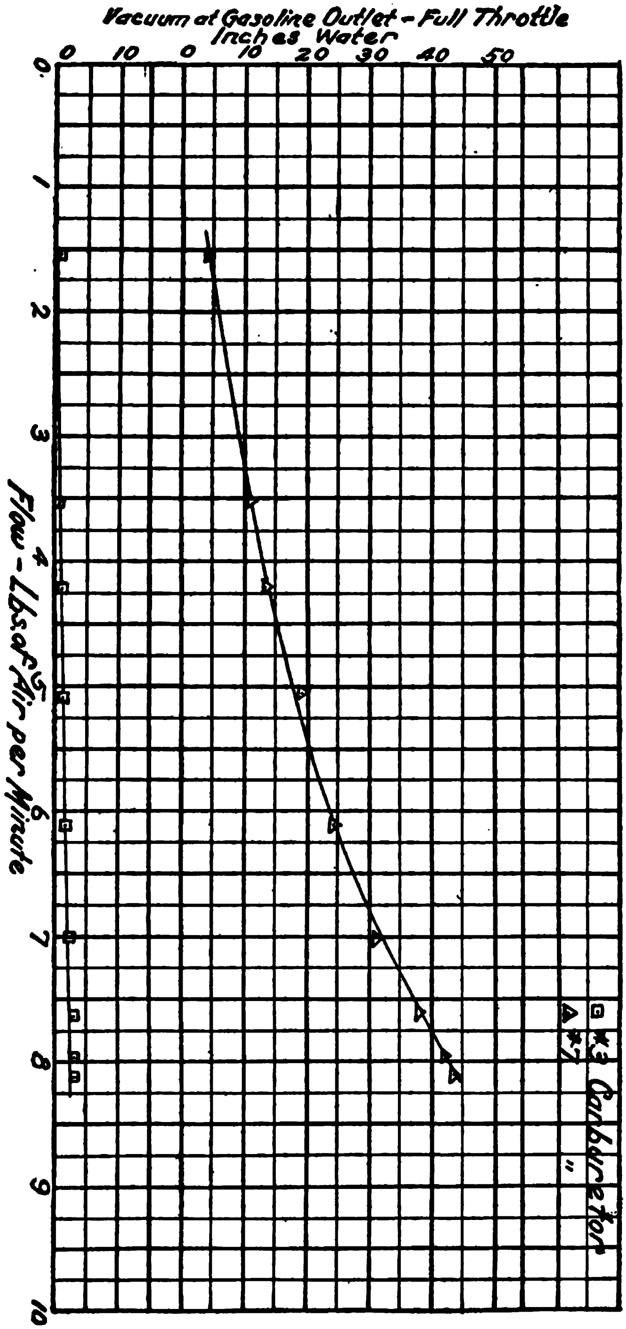

Vacuum at Gasoline Outlet - Full Throttle
Inches Water
0 10 0 10 20 30 40 50
0 1 2 3 4 5 6 7 8 9 10
Flow - Lbs. of Air per Minute
□ #3 Carburetor
△ #7 "

Fig. 55.

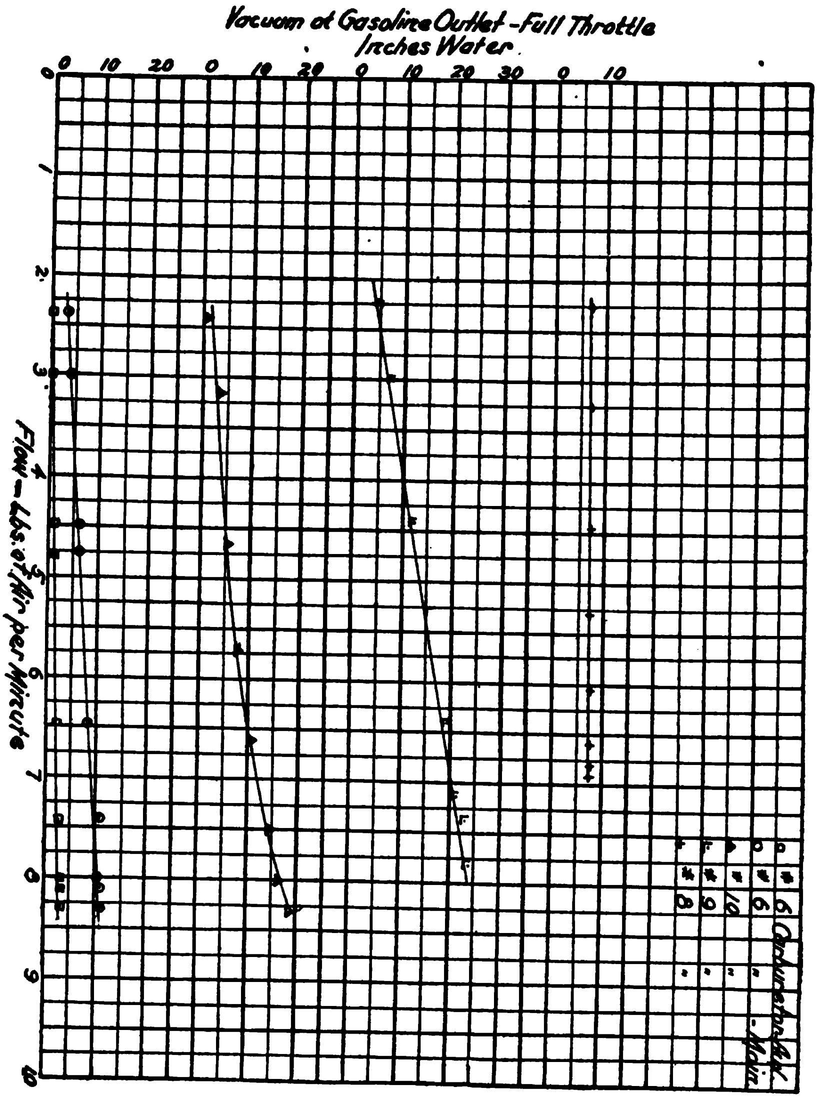

Vacuum at Gasoline Outlet - Full Throttle
Inches Water.
0 10 20 0 10 20 0 10 20 30 0 10
Flow - Lbs. of Air per Minute
0
1
2
3
4
5
6
7
8
9
10
Carburetor Aux.
- Main

Fig. 58.

and the proportionality plotted with reference to flow rates, one curve for each such throttle position, it is a perfectly simple matter to connect the curves representing different throttle positions in any manner desired. The intersections will give the variation in mixture proportions when opening or closing the throttle.

(3) Inspection of these curves immediately raises the question of carburetor capacity rating in terms of flow rate. There is no reason why a manufacturer can not rate a carburetor in any way he sees fit, and there does not seem to exist an accepted standard of capacity. One report of a carburetor test speaks of 120 cubic feet per minute as the rated capacity of an 1½-inch carburetor, but no reason is given. In the light of the results of these new tests 100 cubic feet would seem to be nearer the mark than 120, since in several cases the compensation begins to fail at about 8 pounds of mixture per minute. There are many practical reasons for a reasonably definite and uniform relation between flow-rate capacity rating and connected pipe size.

(4) The importance of fixing a limit to the variation in mixture proportions that is permissible or advisable is also made clear. This question would have to be answered before the performance of any carburetor tested could be classified as good or bad, and it certainly should be known to any prospective user or designer. It would seem as if no real advancement in the carburetor field could be achieved unless and until the various functions are kept strictly separate. It does not seem right to feed a 12-to-1 mixture when a 14-to-1 mixture furnishes exactly the correct amount of oxygen for combustion. If the 14-to-1 mixture does not give as good results in a given engine as the 12-to-1, the conclusion must be that there are present some interfering influences, after the air and the fuel have been measured out. In the absence of proof that constant proportionality in combining proportions is not the best air-gas ratio for mixtures, the only scientific method is to proportion the fuel and air with the greatest possible accuracy and keep the mixture constant instead of guessing at the answer or arbitrarily making the mixture "a little richer" or leaner than it was before some operating difficulty was encountered. Then the next step would be to ascertain what is necessary so that this chemically perfect and constant mixture will give the best results in the engine.

(5) That there is anything but uniformity with respect to mixture characteristics of existing carburetors, the curves demonstrate better than any written comment. Not even the general slope of the curves is the same.

(6) The pressure drop across the carburetor is synonymous with the manifold vacuum at full open throttle, hence an important quantity, since it affects directly the volumetric efficiency, compression pressure, and negative work on the engine. For the same flow rate (about 7.2 pounds of air per minute) and at full throttle the following pressure drops (in inches of mercury) were observed: Carburetor No. 1, 2.3 inches; No. 2, 2.6 inches; No. 3, 1.5 inches; No. 4, 2.3 inches; No. 5, 1.3 inches; No. 6, 1.5 inches; No. 7, 3.3 inches; No. 8, 1.2 inches; No. 9, 3 inches; No. 10, 2.2 inches. These figures in connection with the cross section of the carburetors speak for themselves.

(7) Tests on the same carburetor, but with two grades of gasoline, gave the expected result: The use of lighter gasoline produced richer mixtures for the same air flow, but the difference is so small that it would be hazardous to give a numerical estimate, in view of the irregularities in proportions.

(8) Considering how little really scientific work has been done in connection with carburetors, it is surprising that they function as well as they do, but the road to further improvements seems clearly outlined.

(B) CARBURETOR TEST LITERATURE.

DISCUSSION OF THE LITERATURE OF OTHER CARBURETOR TESTS.

In an official carburetor competition arranged by the Prussian Government, among others, the following properties were to be investigated by tests and considered in the awarding of prizes: Fuel consumption of engine, output and flexibility of engine, time required to start engine after having stood all night in unheated shed, absence of bad odors, absence of smokiness in the exhaust and of soot in the cylinders. No lengthy discussion would be as striking as the simple enumeration of these items if one were asked to demonstrate how vital a part of the modern motor car the carburetor is; how not only power and economy of operation but also convenience and pleasure of driving depend altogether on the carburetor.

When it is further considered that the carburetor art is 23 years old, as the Maybach carburetor, the prototype of all modern proportioning flow carburetors, was introduced in 1893, it is hard to explain the incompleteness—if not complete lack—of reliable design data. One would think that to review all important carburetor tests undertaken for the purpose of furnishing such data would be a formidable undertaking, but instead of that it must be acknowledged that a careful search of the available literature will disclose less than a dozen reports of investigations that are of any real value to the designer.

In the discussion of one such paper presented before the Institution of Automobile Engineers, England, the president of the institution described the situation as follows (Proc. I. A. E., Vol. V, discussion of paper by Morgan & Wood):

> In my experience the design of the spray type of carburetor is somewhat in the same position as the design and fitting out of a sailing boat. Different men come along and move the ballast to different positions and alter and shift the sail plan about, here and there, and get different results, better or worse; but none of them get the exact results that the designer anticipated or know with any sort of certainty what effect any given alteration will produce.

These words were uttered in 1910, but they are just as true to-day, with this difference only, that in the intervening six years a greater number of men have "come along and moved the ballast and altered the sail plan," so that the results on the whole are perhaps somewhat improved, but in the meantime, also, the problem has been rendered more important, as well as more complicated, due not only to the available fuel becoming more expensive but more difficult to use.

If the tests made in connection with this report, incomplete as they are, will serve the purpose of emphasizing the necessity for more work, careful, scientific, unbiased work, the authors will be well satisfied.

A number of published reports of carburetor investigations which appear most useful at first sight lose their value, partly or altogether, on closer inspection. A report which does not give the details of the measuring appliances and methods by which the readings were obtained and the results calculated is of doubtful value, no matter what the standing of the investigator may be, since the degree of accuracy can not be judged nor can the reader know how far the character of the results has been affected by the test methods.

In this connection also the practice of publishing smooth curves only, without giving individual points or the test log, can not be condemned too strongly. Usually, also, in reports of this sort the curves are extended down to the origin or to zero flow, but no one can tell how far actual readings were carried, and this just at a flow region where the greatest irregularities occur. Another procedure which is not necessarily unscientific but apt to be misleading, and which has been referred to in the discussion of the tests, consists in unduly reducing the scale of one of the variables as compared with the other. This is apt to occur when gasoline flow is plotted against air flow.

Again, some apparently careful and valuable reports lose some of their significance when, after all kinds of other devices have been reported on, the author trots out his own personal pet and shows how superior it is to all the other creatures. As long as this refers only to some pet theory exception can not be taken, but when it is a question of a patented device which is just being put on the market it would seem to be more appropriate to let some one else report on it. No matter how distinguished a man me be, no matter how far above any unworthy suspicion, a scientific test report in which he compares different devices, all in the market and all patented and competing with each other, should not be signed by the inventor of one of the devices.

Some of the most valuable information has been derived from the work of British scientists, and the reports which were all presented before the Institution of Automobile Engineers deserve the highest praise, although some details may be criticized.

In 1907 Dugald Clerk read a paper before the institution on the principles of carbureting, as determined by exhaust-gas analysis. He examined the trials of the Royal Automobile Club. His paper and that of Prof. Hopkinson, of Cambridge University, in the same year, are important because they showed how the carburetor performance might be analyzed by means of the exhaust-gas anaylsis.

In Clerk and Burls Gas, Petrol, and Oil Engines, Volume II, page 632, a simple formula for calculating the air-fuel ratio from exhaust analysis will be found.

Two splendid investigations were undertaken by Dr. Watson in 1908 and 1909. The titles are "On the thermal and combustion efficiency of a four-cylinder petrol motor" (Proc. I. A. E., Vol. III, p. 389), and the other, "An investigation of the thermal efficiency of a two-cycle petrol engine" (Proc. I. A. E., Vol. V, p. 83). As the titles show, they were not really carburetor tests, but since they were to be as complete engine tests as facilities allowed, both air and fuel were measured, and the exhaust gases were analyzed. Thus the re-

sults, while not dealing with the performance of a modern carburetor under all conditions of flow (all tests were run at full throttle and the auxiliary air valve was fixed), are of the greatest interest as showing the relations between economy and mixture proportions and between exhaust gas analysis and mixture proportions. The tests were deficient only as far as the loading of the engines was concerned. In one case an uncalibrated fan brake was used; in the other a belted dynamo, so that in neither test could the brake horsepower be determined. Dr. Watson used an optical indicator of his own design, and all results are referred to as indicated horsepower. The air was measured by means of an orifice in a thin plate, forming the inlet to a box from which the air was drawn. The primary and the auxiliary air inlets of the carburetor were connected to the box by a pipe. A box of 19 cubic feet volume was used, but this was not sufficient to damp the pulsations of the air, so on one side of the box was an india rubber diaphragm. This is a very simple arrangement, and quite accurate if plate and orifice are made the same as those used in some reliable calibration tests, such as, for instance, Durley's experiments, so that the coefficient is known. It has, however, the disadvantage that the range of flow which can be measured with one diaphragm is very limited, since any large pressure drop must be avoided. This would mean a number of plates and orifices which would have to be exchanged when any flow rate between 120 cubic feet per minute and less than 1 cubic foot is to be measured, as was done in the new tests of this summer here reported. Of great importance in Dr. Watson's report are the graphs giving the relation between CO_2, CO, O_2, and the proportions of air to fuel.

Very interesting also, although not quite as accurate perhaps, are the tests made by Messrs. Morgan and Wood, and presented before the Association of Automobile Engineers the same year (1910) as Dr. Watson's second paper (Proc. I. A. E., Vol. V, p. 37). The purpose of the investigation was to develop a kerosene carburetor. The mixture was pulled through an automobile engine, which was driven by outside power, and then it was discharged into a gas holder for measuring. A rather risky procedure, it would seem. First, simple carburetors made up of sections of pipe and spray orifices were tested, and the characteristics of plain tube carburetors developed. Then regular carburetors were put under test, single jet with mechanical air valve, single jet with spring-controlled air valve, two and three jet and mechanical air valve, etc. The final conclusion of the authors was that a plain tube carburetor with fixed fuel nozzle of the right proportions could be combined with a constant rate of flow nozzle so as to produce a mixture of constant proportions. This would lead to a type of carburetor similar to our No. 4. Examination of the curves will show that most of them are quite irregular, although the general tendency may be evident. The individual points are given only on some of the plots. The tests were made at full throttle. Important, too, is the statement, which should be obvious, but does not seem so to many people, namely, that the tests when reproduced with the engine running under its own power gave exactly the same results.

In the discussion of this paper reference is frequently made to "surging flow" in the suction pipe, organ pipe effects, which possibly might affect the results.

In the Zeitschrift des Vereins deutscher Ingenieure a number of accurate and complete engine tests have been published from time to time, and Prof. Riedler, of Charlottenburg, has carried on a great many interesting engine investigations, but no special carburetor investigation has been found in the German technical literature except two. One, of course, is Prof. Rummel's, Aachen, Germany, famous investigation, which correctly has been called a classic of carburetor literature. Prof. Rummel conducted an extensive series of tests covering a period of three years to determine the laws of flow from carburetor nozzles. The results were first published in Der Motorwagen in 1906, and lately have been published in translation by Horseless Age, April 14, 1915. Since these experiments were not made on actual carburetors, but on nozzles only, and not in connection with an engine, they are reviewed in connection with the discussion of flow laws.

The same procedure has been followed in the case of R. W. A. Brewer, whose work would have been reviewed, together with that of the other British investigators, if it had not principally dealt with the establishing of flow laws based on the experiments of others and himself. E. Sorel's, the French engineer, valuable contributions are also treated in the last chapter.

Returning to carburetor investigations carried on in Germany, we find one and, as far as is known to the authors, the only instance where an attempt was made to determine the actual performance of existing commercial carburetors by means of unbiased competitive tests. These tests were undertaken by a commission appointed by the Prussian Government for the purpose of finding the carburetor best suited for benzol fuel. Money prizes were offered, and 14 carburetors were entered. A description of the test methods and of the prize-winning carburetors will be found in Der Motorwagon, May 31, 1914, and Horseless Age, volume 33, page 640. Unfortunately the actual results, which must be of extreme interest, have apparently never been published, probably due to the outbreak of the war. Nevertheless, it seems appropriate to call attention to the test conditions in view of the desirability of undertaking similar work in this country.

The tests consisted of two parts, a laboratory test and a road test. The bench tests were run in the laboratory of the Technische Hochschule, Charlottenburg, where the carburetors had to be attached to a pleasure car engine and a truck engine, all carburetors, of course, being tested on the same two engines. The points on which the carburetors were to be judged in the bench test were: (*a*) Maximum power; (*b*) fuel consumption at maximum power; (*c*) consumption when throttled, at R. P. M.=1,400; (*d*) consumption when throttled, at R. P. M.=800; (*e*) lowest R. P. M. at full load; (*f*) lowest idling speed; (*g*) fuel consumption when idling; (*h*) flexibility under sudden changes of load. Whether the order also represents the order of merit in judging is not clear. The exhaust was analyzed by Orsat apparatus. Also determined were the volumetric efficiency of the engine, cooling water temperature, humidity of the air, temperature of the air. All results were reduced to normal barometric reading. It was found that one of the leading carburetors could be used either on gasoline or benzol fuel without any change whatsoever. A route

extending over several hundred miles was laid out for the road tests. The points for the latter (partly quoted at the beginning of the chapter) were as follows: Consumption of benzol; output and flexibility of engine; time required to start engine after the car had stood all night in an unheated shed; absence of bad odors, of smoke in the exhaust, or soot in the cylinders; accessibility of internal parts; rapidity of conversion for operation on gasoline; and consumption of gasoline over one stage that had already been driven over on benzol.

Who can doubt that a competition of this sort properly conducted will be of incalculable benefit to the state of the art not only but to the whole industry? One only has to think of the stimulus given to the aeroplane-engine industry by the competitions that were held by the various European Governments and associations.

Coming now to the experimental work done in this country, we find that many have tried earnestly enough to solve the great mystery, but the net results, as far as the advancement of the art is concerned, are deplorably deficient. This statement, of course, refers only to the results published and not to the experimental work which has been carried on by the carburetor and automobile manufacturers and in private laboratories, and about which nothing is officially known. A great many individuals have experimented on carburetors, but in most cases either the mental equipment and scientific training of the investigator or the mechanical equipment for the carrying out of the tests, or both, were wholly inadequate to the task. No wonder then that men would come to such conclusions as this: "The investigation furnished convincing evidence that combustion is entirely without law; in other words, that it is an empirical phenomenon and to be treated as such."

A few of the serious investigations which have been found in the trade literature and proceedings of societies will now be briefly reviewed.

C. H. Taylor published in Horseless Age (Mar. 4, 1908) the results of tests made by him in order to determine correct mixture proportions for different engine speeds and throttle positions. The report is quite complete and great care apparently was used in order to obtain exact results, but the test equipment can not be accepted for a scientific investigation. The air was measured by means of an ordinary gas meter and the gasoline determined from the number of revolutions of a calibrated small triplex pump driven from the engine by friction drive. The gasoline pipe was heated by a blow torch and the supposition was that the gasoline entered the air pipe in vapor form. A two-cylinder automobile engine was used for the tests.

D. S. Tice undertook some experimental work described by him in Horseless Age, August 19, 1908, for the purpose of establishing definitely just what law or laws are followed by the discharges of several nozzle forms in actual use in carburetors. The nozzles, actually taken from carburetors, were tested by themselves, actual conditions being reproduced as far as possible, with the engine suction replaced by an aspirator. Gasoline flow is shown plotted against pressure drop. The air flow is calculated from theoretical formulæ without using a coefficient. In his conclusions Mr. Tice proposes in place of the automatic air valve as one means of compensation, "a jagged

piece of metal placed in the fuel passage in such a way that it presents a great frictional resistance to the flow of the liquid at high velocity, thus reducing the nozzle efflux," which is rather interesting in view of the fact that a similar method has lately been not only proposed but actually introduced in a carburetor. More about this will be found in the discussion of flow laws.

J. S. V. Bickford (Horseless Age, Dec. 2, 1908) constructed experimental carburetors out of glass lamp chimneys and nozzles and measured the air by means of a homemade gas holder consisting of a tinplate bell and a water barrel.

Mr. Tice's and Mr. Bickford's tests were used by H. L. Hepburn (Horseless Age, Apr. 14, 1909) as the basis for calculations on the carburetor problems.

A paper was read in 1912 before the American Society of Mechanical Engineers by George W. Munroe describing the tests he made on six commercial carburetors. The carburetors were attached to a new four-cylinder automobile engine, the load was applied and measured by means of an ordinary Prony brake. In each run power, speed, and fuel consumption were determined, but the air was not measured nor was the exhaust analyzed, so that the results are of no help in the proportioning problem. Tests were run at 10 different speeds, maximum load for each speed, and then the speed was reduced by throttling, so that the results should give a complete picture of engine and carburetor performance under all conditions of steady running, but of course this over-all performance does not assist the designer very much in tracing the reasons for good or bad results.

S. M. Udale (Horseless Age, Aug. 6, 1913) discussed the method and interpretation of exhaust-gas analysis in engine and carburetor tests. This method was first applied to automobile tests by Dugald Clerk (Proc. I. A. E., Dec. 11, 1907), as mentioned before, and undoubtedly is most helpful in the interpretation of results when considered in conjunction with air and fuel measurement, but just because the taking of samples and the use of the Orsat apparatus seems so very simple, exhaust-gas analysis is a rather dangerous thing. Only in the hands of a skilled chemist or of some one who has taken the trouble to study the subject and knows what to guard against, the Orsat or similar apparatus will furnish reliable results. It is rather significant that Mr. Udale in 1913 had to use the results obtained by Mr. Taylor, given years previous (see above), in order to illustrate some of his deductions, bearing out what was said at the beginning of this chapter about the meagerness of test data published.

The technical committee of the Automobile Club of America made a test of the "Sunderman safety carburetor," which was published in Horseless Age of October 1, 1913. At various speeds the horsepower and the fuel and air consumption were determined, and the exhaust gases were also analyzed. A Venturi meter was used for the air measurements. A number of runs were also made with the throttle valve being periodically opened and closed.

Under the auspices of the Automobile a series of road tests were undertaken, pleasure cars as well as motor trucks participating. The results were published in the Automobile, February 12, 1914, and February 19, 1914, by Mr. Herbert Chase. The gasoline was measured and exhaust gas samples were taken at prescribed points of the

route. The results together with the specifications of the cars are given in the report. In almost every case the percentage of CO when idling was very large.

At various times Messrs. F. H. and F. O. Ball have contributed the results of carburetor investigations. Thus we find articles by these authors in Horseless Age, December 25, 1907, in the same publication under the date of August 4, 1909, and finally a paper presented before the Society of Automobile Engineers and published in the Society of Automobile Engineers' Bulletin of August, 1916, all of these dealing with carburetor investigations carried on by the authors in their own laboratory. The testing equipment is only vaguely described. An engine with electric brake which could also run as motor, as well as a steam ejector, were used to draw the air through the carburetors. What kind of air-metering equipment was used is not stated except that it was "calibrated and very accurate." Many carburetors were tested, and the results are plotted as curves with the ratio "gasoline, ounces per 1,000 cubic feet as ordinates and air flow in cubic feet per minutes as abscissae." On each curve sheet the region between best ratio for high power and best ratio for high efficiency is shaded, there may be and is, of course, a difference of opinion about the numerical value of these limits. At the end of this year's paper a new two-stage carburetor is described and its performance analyzed. According to the curves it gives an absolutely constant ratio between 40 and 140 cubic feet per minute air flow. Individual points are not given. Tests are also given for a carburetor with "friction control" of gasoline. By compelling the fuel first to travel through a long thin annulus of relatively large diameter the authors claim to regulate the flow so that it will be directly proportional to the head itself instead of to the square root of it, and since, according to them, the flow of air in a carburetor with a spring loaded auxiliary air valve varies directly as the head, constancy of proportions is assured. An interesting discussion follows the paper.

The results of a diligent search of all publications to be found in the libraries of New York City are contained in the above review and it is thus seen that the private inventor or the small manufacturer who has not the means to install and maintain the elaborate testing equipment required, has almost no reliable data to help him in his work. This explains the many failures and disappointments among the great number of enthusiastic and conscientious people who have been lured into the field by the attractiveness of the carburetor problem.

REPORT No. 11.

PART VII.

CONCLUSIONS AND RECOMMENDATIONS.

By Charles E. Lucke.

1. Carburetor design has not yet emerged from the stage of invention and empiricism, but the time has arrived when it is important that scientific engineering methods should govern the practice in design.

2. There is available a surprisingly large number of different forms and arrangement of parts constituting carburetor schemes in the Patent Office records which serve as excellent material for qualitative design, to which the necessary dimensions must be applied when sufficient data have been established. (See Part IV of this report.)

3. Data are lacking on air and fuel flow in carburetor passages necessary for the determination of such dimensions as will insure the production of a specified quantity and quality of mixture. Quantitative design can not be undertaken until such data have been established. (See Part V of this report.)

4. Data are also lacking on the mixture requirements for engines to insure their best performance in horsepower and efficiency, which engine mixture requirements constitute the specifications which the carburetor must fulfill. (See Part I of this report.)

5. Experimental determination of the relation between the rate of flow of fuel and the head should be undertaken for all grades of gasoline, kerosene, alcohol, and benzol in passages of size and shape suitable for carburetors, and at all rates of flow from zero up to the maximum used. The sizes of passage should extend from zero up to values suitable for the largest gasoline engines, which, for the present, may be set at 500 horsepower, in round numbers. The effect of temperature and viscosity must also be evaluated over a range in excess of what may be encountered in use.

6. Experimental determination of the relation between the rate of flow of atmospheric air into carburetor air passages and the vacuum at any point of the passage should be undertaken for such shapes and sizes of air passages as are suitable for carburetors of the various compensating classes and for all velocities from zero up to the critical for orifices. The effect of changes in barometric and absolute pressure and of temperature on the air flow-vacuum relation should also be evaluated over a suitably wide range with reference to use.

7. The accuracy of maintenance of proportion in present commercial carburetors over working ranges of flow rates and at different throttle positions is by no means as good as it can be made. (See Part VI of this report.)

8. Additional tests on the changes in proportion of air to fuel in commercial carburetors should be made to clearly establish the influence of (*a*) sudden opening or closing of throttle; (*b*) atmospheric temperature between 120° F. and —30° F.; (*c*) air pressure from 10 to 40 inches Hg. absolute; (*d*) tilting through at least 45° from the vertical in all horizontal directions; (*e*) vibrations of such periodicity and degree as is characteristic of each typical arrangement of engine parts and for the largest and smallest sizes; (*f*) mixture pipe pulsations of the periodicity and amplitude found in typical manifolds of varying length and for all types of cylinder grouping.

9. Additional proportionality tests should be undertaken on two groups of carburetors and two types of engines. One of the carburetors should have throttle controlled compensation, and the other a compensation automatically controlled by the flow rate, independent of the throttle. One of the engines should have a load or resisting torque, independent of speed, and, therefore, the carburetor flow rate will be independent of throttle position, typical of automobiles. The other engine should have a resisting torque that is a function of speed, and, therefore, the carburetor flow rate will be more or less fixed by throttle position, typical of aero and marine conditions. These tests will clear up the question of the relative value of the two types of load, and especially for the screw propeller load—prove whether or not the throttle controlled compensation is substantially as good as the automatic, which appears to be necessary for the automobile type of load. In the test with propeller loads the propeller torque influences introduced by variable air or water currents must be evaluated.

10. The engine test to be conducted for the purpose of determining the most suitable mixture specifications should be started with mixtures that are dry and such as are most easily made by using very light gasoline of 76° Baumé or better. With such a fuel the precise effect of the proportion on both maximum horsepower and thermal efficiency should be determined for each type and size of engine now in use. Subsequently, heavier gasoline should be used, such as will yield mixtures with increasing amounts of unvaporized fuel, while the mixture proportion is first kept constant and then varied so that the effect of proportionality and of volatility or mixture wetness may be known on engine capacity and efficiency. Finally, each of the wet mixtures should be dried by heating and the effect on engine capacity and efficiency again determined. From the results of such tests the mixture specifications can be quantitatively fixed as to proportionality and quality and density with allowable limits to give any required engine performance, and carburetors can be purchased on such specifications or can be designed to fulfill them, fulfillment being determined by test.

REPORT No. 12.

EXPERIMENTAL RESEARCHES ON THE RESISTANCE OF AIR.

By L. MARCHIS,
Professor in the Faculty of Sciences, University of Paris, France.

REPORT No. 12.

EXPERIMENTAL RESEARCHES ON THE RESISTANCE OF AIR.

By L. Marchis.

CHAPTER I.

CLASSIFICATION OF EXPERIMENTAL METHODS.

1. REACTIONS EXERTED BY THE AIR ON A BODY IN RELATIVE MOVEMENT WITH IT.

When a body is in movement relative to the air with which it is surrounded, it is subject to a system of forces to which is given the name of "reactions exerted on the body by the air." These reactions are variable, especially as regards (1) the form of the body, (2) the position which it occupies in relation to the surrounding medium, (3) the various circumstances of its movement (time elapsed from origin of movement to present moment—velocity relative to the air), and, finally, (4) the mass of the fluid which surrounds the body in movement.

We shall not develop in detail the difficultics presented by each of these problems, of which certain have reccived only very imperfect solutions.

We shall, in what follows, consider only the case of a body surrounded completely by a great mass of air, rclative to which it has a movement, established a long time previously, and of which the velocity and direction are constant and readily determined.

The reactions exerted by the air on the body in movement relative to it are reduced to a force and a couple. We shall assume that the body under experiment possesses, at the least, a plane of symmetry, thus eliminating the couple from the reactions of the air and reducing them to a single force, to which we shall give the name of "resistance of the air on the body in movement relative to it."

When we consider the movement of the body relative to the air which surrounds it, we have not only in view a movement of translation, but also a movement of simple rotation and likewise a movement of rotation combined with a movement of translation. In other words, we shall study here the problem of the propeller as well as that of the wings of an airplane.

2. MANNER OF PRODUCING THE MOVEMENT OF A BODY RELATIVE TO THE AIR WHICH SURROUNDS IT—BODY MOVABLE.

Various experimental methods may be utilized in order to produce the movement of a body in reference to free air.

In an indefinite mass of air, at rest as a whole, the following types of movement may be given to the body:

(a) A movement of rectilinear translation;

(b) A movement of rotation about the axis of a mechanism;

(c) An oscillating movement, as in the case of a pendulum.

The methods by means of some form of mechanism or by means of a pendulum have been but little employed in France and we shall omit special reference to them.

The method employing the motion of translation may be applied in two forms:

(1) The body is allowed to fall freely in air, as calm as possible.

(2) The body is carried on some form of car which is moved in calm air.

In France the method of free fall has given rise to important investigations made by MM. Cailletet and Colardeau and especially by M. G. Eiffel.

The method by means of a car is now utilized by the Aerodynamic Institute of Saint-Cyr, at the laboratory of military aerostation of Chalais-Meudon, and also by M. the Duke of Guiche. At Saint-Cyr and at Chalais-Meudon, the car is composed of a carriage moving on rails. M. de Guiche employs an automobile as a carrier.

A variant of the method of the car has been installed at the laboratory of military aviation at Vincennes. On a stretched cable a little hanging car rolls, carrying, attached below it, the objects under test with the necessary instruments.

The dimensions of the bodies on which the experiments are carried out may be of the order of those which are utilized in aviation itself. In other words, it is possible to operate upon equipment as used in actual aviation, or at least presenting dimensions differing but little from those used in practice.

From this point of view the method by displacement through the air opens up a field of investigation more extended than the method in which an artificial current of air is employed.

3. MANNER OF PRODUCING THE MOVEMENT OF A BODY RELATIVE TO THE AIR WHICH SURROUNDS IT—ARTIFICIAL CURRENT OF AIR.

It is possible, in fact, to realize in an entirely different manner the relative movement of a body through the air.

Instead of moving the body under test, a fixed position is given to such body placed in an artificial current of air.

The body may then be disposed in the free air in front of the orifice through which the air enters under regulation by means of suitable devices. This method has been employed by M. Rateau.

The body under investigation may also be placed in an inclosure or integral part of the apparatus for the regulation of the current of air. It is placed, for example, in a part of a large cylindrical pipe which receives a current of air produced by a fan and of which the velocity, at a certain distance from the walls, has been rendered sensibly parallel to the pipe.

This method, furthermore, may be subject to certain variations:

(a) The body under investigation alone is placed in the inclosure in the interior of which the artificial current of air is produced. The apparatus for measuring the reactions of the air are on the exterior of this inclosure, their connection with the interior being made through the solid wall which limits the conduit.

This method is known under the name of the "tunnel method." It has not been largely employed in France. There exists at the present time at the Aerodynamic Institute of Saint-Cyr a tunnel of which the practical use has been interrupted by the present war.

(b) The apparatus employed for determining the circulation of the air is enlarged into a chamber of suitable size, traversed between two of its parallel walls by a cylinder of moving air. On the outside of the latter and within the chamber arè located the experimenters with the necessary measuring apparatus.

We propose to call this the "Eiffel method."

In France this method has given very complete results. It is for us the characteristic method in connection with the use of an artificial current of air.

From the point of view of the convenience of carrying on the experiments, especially in large numbers, the last method is superior to the method by displacement in free air. The latter demands, in fact, that the external air shall be as calm as possible. This condition can only be realized on certain days and then only for certain hours of a given day. If along the right-line path of the body under investigation the wind should have everywhere the same intensity and the same direction, due allowance might be made for its existence.

But many investigations, notably those of M. Maurain at the Aerotechnic Institute of Saint-Cyr, show that at any given point in the air the wind is frequently subject to continued changes in direction and intensity.

But even if it allows the experimenter to regulate the conditions of any one investigation, the method by the use of the artificial current of air can only be applied to models reduced in size in comparison with actual practice in aviation. We shall see later the reason for this limitation.

One question immediately presents itself: How may the results obtained in the study of models be transformed in order to furnish information applicable to apparatus of full size? What is the law of similitude which makes possible the transformation of an investigation on a small scale to corresponding phenomena on a large scale. This is the matter which we shall especially develop at a later point.

A further question presents itself: Do the methods mentioned above, namely, the displacement of the body under investigation and the method by the artificial current of air, lead to the same results? M. Eiffel maintains the affirmative, relying upon the fundamental principle of relative movement. M. de Guiche maintains the negative, arguing that the tunnel method does not realize fully the conditions which permit the application of such a principle.

We shall return to this question at a later point, in connection with the comparison of the results obtained by these two experimenters.

4. STUDIES OF AIRPLANES IN FREE FLIGHT.

The methods which we have just considered require that the body under investigation be connected in a fixed manner with a support. The latter has, under good conditions, its dimensions reduced as much as possible. It is also removed as far as possible from the body under investigation, so that its presence will produce the minimum of disturbance. It is none the less true, however, that the airplane, thus studied, is not in the precise condition of free evolution in the open air.

For this reason investigations have been undertaken on airplanes during their free flight in the air. Unfortunately, the field of such investigation is limited. It can not be carried through at the will of the experimenter; that is to say, of the pilot, who must first of all guard against danger of fall. Such experiments give complex results often difficult of analysis. Nevertheless it can not be denied that such results may have a very considerable practical value.

Experiments of this character were inaugurated in 1910 by MM. Gaudart and Legrand with a Voisin biplane. These experiments were, however, neither sufficiently systematic nor numerous to lead to significant results.

Quite otherwise are the researches made by Commander Dorand, at Villacoublay, on a biplane of his own construction piloted by M. Labouchère. At the Institute of Saint-Cyr, MM. Toussaint and Lepère, Toussaint and the Lieutenant of Aviation Gouin, have made important experiments on a Maurice Farman biplane and on a Blériot monoplane. Ingenious apparatus capable of registering the movement of the pilot was employed to furnish important indications regarding the operation of such actual aviation equipment.

5. THE TOTAL RESISTANCE OF THE AIR AND THE DETERMINATION OF THE PRESSURES AT EACH POINT OF THE SURFACE OF THE BODY UNDER INVESTIGATION.

Let us return to the methods which, in a laboratory, may be employed in determining the resistance of the air upon a body in movement relative to it.

With regard to the method of measuring this resistance two types may be characterized:

(1) Determination, by means of a balance, of the total resistance on the entire body under investigation.

(2) Determination, at each point of the body, of the reaction exerted by the air at this point; a study, in some manner topographical in character, regarding the pressures resulting from the relative movement of the body and the air.

This investigation immediately leads, through a geometrical composition of the individual forces thus determined, to a knowledge of the complete resistance of the air.

The method by means of the balance has given wonderful results in the laboratory of M. Eiffel and at the Institute of Saint-Cyr. M. de Guiche has applied this method solely to the analysis of the distributed pressures.

Such is the general classification of the experimental methods at present in use in France for the study of the problems of aerodynamics. We proceed to give in detail the fundamental principles of these investigations in a further study of the French aerodynamic laboratories.

CHAPTER II.

THE AERODYNAMIC LABORATORIES OF FRANCE.

1. THE EIFFEL LABORATORIES—EXPERIMENTS MADE AT THE EIFFEL TOWER.

The Eiffel Tower was the first laboratory utilized by the celebrated engineer in his researches in aerodynamics, carried on during the past 10 years. Bodies thrown from one of the platforms of the tower have permitted a study of free fall in calm air.

The study of this movement admits, furthermore, of being made by two different methods.

The first of these methods consists in determining the velocity of uniform movement which succeeds the varying movement. To this velocity corresponds a resistance of the air equal to the weight P of the body. By augmenting the weight of the body without changing the surface, as by the addition of suitable ballast, it is possible to increase, at the same time, the limiting uniform velocity V of the movement. The comparison of the different values of P with the corresponding values of V provides a means for developing a law of variation of resistance as a function of velocity. Such is the principle of the method applied in 1892 by Cailletet and Colardeau from the second story of the Eiffel Tower (120 meters = 394 feet above the ground).

Instead of limiting himself to the study of that part of the free fall that corresponds to uniform movement, M. Eiffel registers the values of the velocity and of the resistance of the air at each instant of the fall. The principle involved in this investigation is the following:

The surface under investigation, a plane for example, falls freely, remaining horizontal. It is supported by a spring, of which the displacements are inscribed on a cylinder revolving with a velocity directly proportional to that of the fall of the system under investigation. The compression of the spring, as a result of the resistance of the air, gives rise to a force which, by a suitable calibration, may be determined as a function of the displacements of this spring. This force produces equilibrium with the following system of forces

(1) The weight of the system.
(2) The forces of inertia which act upon it.
(3) The resistance of the air.

It is then possible to calculate this last force when the acceleration of the system is known. To this end it is sufficient to inscribe, by means of a tuning fork, the time of fall on the same cylinder whereon are recorded the compressions of the spring.

In a certain experiment, when the combined weight of the plate with its spring and support was 4.494 kilograms (9.887 pounds), the

following determinations were made, in one case at the end of 60 meters of fall (196.8 feet) and in the other case at the end of 95 meters (311.6 feet):

At the end of 60 meters:		
Force of inertia	3.76 kg.	
(Absolute value.)		
Tension of spring		4.15 kg.
Resistance of the air		4.90 kg.
Difference		=0.75 kg.
At the end of 95 meters:		
Force of inertia	3.36 kg.	
(Absolute value).		
Tension of spring		6.15 kg.
Resistance of the air		7.30 kg.
Difference		=1.15 kg.

These numbers show that under the existing conditions (total weight of plates, of spring, and of support rather high) the difference between the tension of the spring and the resistance of the air is clearly measurable.

By this method, M. Eiffel has studied the resistance of the air on planes of which the surfaces varied from 1/16 square meter (0.67 square foot) to 1 square meter (10.77 square feet) and of which the velocities of fall ranged between 18 and 40 meters per second (59 to 131.2 feet). These high velocities have made it possible to operate in the open air with high precision in calm weather and as long as wind velocities did not exceed 2 to 3 meters per second (6.56 to 9.84 feet per second). The results obtained by these experiments are excellent for planes falling horizontally. They are less worthy of confidence for planes inclined to the vertical.

2. THE EIFFEL LABORATORY—METHOD BY THE USE OF AN ARTIFICIAL CURRENT OF AIR.

This method, which consists in placing a model in the cylinder of air flow created by a fan, should be applied with the following precautions:

(1) It is necessary that the model should be placed in a mass of air theoretically indefinite, practically very great, and having a velocity constant in magnitude and in direction.

The section of the cylinder of air should be sufficiently large, in order that at the periphery the velocity of the air may be sensibly the same in magnitude and in direction as that of the air which has not yet approached the obstacle. In this method it is necessary to realize, first of all, a cylindrical current of air, and then to introduce into this current a body of dimensions so small by comparison that its presence shall not produce any sensible disturbances at the periphery of the current. Experience has shown that the ratio of the greatest dimension of the model to the diameter of the cylindrical current should not exceed 45 per cent.

(2) It is very necessary that the model under investigation shall be practically isolated in the current of air; that is to say, that the support of the model shall play only a negligible rôle and shall introduce no perturbations of importance.

(3) It is necessary that the model adopted shall not be too small in size if it is desired to extend in a more or less significant manner the results obtained with such model to full-sized apparatus.

In fact, when a study is made of the distribution of pressure over the various points of a plate, for example, either on the face directly exposed to the action of the current of air, or on the reverse face, it is found that this distribution becomes regular only at a certain distance from the border. There exists, both in front and behind, a central zone in which a regular regimen is established, which is manifest by isobars parallel to the forward edge. In order that this central zone may be studied, it is necessary that the dimensions of the plate under investigation be sufficiently large. In fact, the width of the marginal zone in which the pressures are irregularly distributed does not vary proportionally with the dimensions of the plate. The experiments of M. de Guiche show that this width varies but little with the dimensions of the plate. In operating on thin rectangular planes with the attacking edge perpendicular to the direction of movement, M. de Guiche has found that the marginal bands of irregular condition have a sensibly constant width, equal to 20 centimeters (7.88 inches) in front and to 40 or 50 centimeters (15.76 to 19.7 inches) at the rear. He concludes that it is well not to operate with planes having a spread less than 1 meter (3.28 feet). In the study of curved surfaces, M. de Guiche found marginal bands of disturbance of which the sensibly uniform width scarcely exceeded 20 centimeters (7.88 inches) on the two faces. It is well, therefore, to use only surfaces whose spreads are superior to 40 centimeters (15.76 inches). When lesser spreads are employed the results obtained by the use of small models do not permit of deducing, in a sufficiently precise manner, the results which would be given by the wings of an airplane of normal size. In the case of very small models the mode of distribution of pressure has but a very remote relation to that which would be found on wings of normal dimensions.

This condition of only using, for experimental purposes, models of sufficient dimensions leads, in the method by the use of an artificial current of air, to the employment of very large sections for the cylinder of air. For example, a study of planes having a spread of 1 meter (3.28 feet) can only be made in a cylinder of air of which the diameter is greater than 100/.45 = 220 centimeters (86.7 inches), approximately. As to curved surfaces, it would be sufficient to provide a cylinder of a diameter greater than 40/.45 = 89 centimeters (35 inches), approximately.

In France, M. Rateau has utilized the method by the use of an artificial current of air. His apparatus comprises the following items:

(1) A helicoidal fan, 1.2 meters diameter (47.3 inches).

(2) A wooden chamber, 1.5 meters on the side (59.1 inches). The purpose of this chamber is to suppress, by means of suitable partitions, the turbulence produced by the fan and to create a current of air with the velocities of movement equal and parallel throughout

(3) An outlet orifice of 0.7 meter (27.6 inches) diameter from whence issues a cylindrical current of the same diameter.

(4) A weighing balance located in the outside air at a little distance from the orifice through which the current of air issues.

Such an apparatus would permit of realizing velocities of the air reaching 35 meters (114.8 feet) per second. The diameter of the cylinder of air, however, is too small. M. Rateau was not justified in introducing into this current plates 30 by 50 centimeters (11.8 by 19.7 inches) or biplanes 15 by 50 centimeters (5.9 by 19.7 inches) (separation of planes 20 to 30 centimeters = 7.9 to 11.8 inches). The supports of the objects under investigation and of the measuring equipment were too large, causing very considerable perturbations. The experiments of M. Rateau should be noted as of historic interest, but they can be scarcely considered as having a definitive value.

Much more complete and certain are the results obtained by the installation of M. Eiffel. The Eiffel apparatus comprises the following items:

(1) An orifice from which issues a cylindrical current of air.

(2) An experimental chamber where the air is at a pressure less than normal and where are located the experimenters and the measuring apparatus.

(3) A diffuser.

(4) A fan placed at the end of the diffuser.

The current of air which enters through the orifice in the wall of the experimental chamber and which leaves through the opening of the diffuser placed in the wall opposite and parallel to the first, is a current of air produced by aspiration and not by pressure, as in the installation of M. Rateau. The aspiration removes the influence due to the turbulence produced by the fan, and a regulating box for the current of air in front of the orifice is not necessary. However, certain grillages placed in the openings for entrance to and issue from the experimental chamber play the rôle of regulators for the current of air.

In the laboratory of the Champ de Mars the fan was placed near the opening through which the air leaves the chamber. A large conduit of wood received the air issuing from the fan and, gradually reducing in size, conducted it through a passage ending in the shed, whence the air was drawn into the orifice through which it entered the experimental chamber.

The cylinder of air had a diameter of 1.5 meters (59.1 inches).

The maximum velocity of this air was equal to 18 meters (59 feet) per second, or 65 kilometers (40.4 miles) per hour. The fan employed, of the centrifugal type, delivered 31 meters^3 (1,095 cubic feet) per second, corresponding to a velocity of 18 meters per second and to the circular section of 1.5 meters diameter, requiring 60 horsepower.

The laboratory installed at Auteuil by M. Eiffel is much more powerful. The cylinder of air of the large equipment has a diameter of 2 meters (6.56 feet). Velocities of the air may be realized from 2 to 30 meters (6.56 to 98.4 feet) per second. A second smaller cylinder of air, having a diameter of 1 meter (3.28 feet), parallel to the first, provides velocities from 2 to 40 meters (6.56 to 131.2 feet) per second.

The 60 horsepower is, however, not exceeded in this new installation, in which the delivery of 90 cubic meters of air (3,179 cubic feet) per second may be realized, corresponding to the circular section of 2 meters diameter and a velocity of 100 kilometers (65.14 miles) per hour.

This increase in efficiency is realized by interposing between the experiment chamber and the fan a divergent orifice forming a diffuser. This diffuser has a diameter equal to 2 meters at the outlet from the chamber; it connects with the ring of a helicoidal fan of 3.8 meters diameter (12.46 feet), providing for the flow of the air a useful section of 9 square meters (96.9 square feet). The reduction of velocity which is produced by passing through the diffuser, as a result of the progressive increase in diameter, raises the pressure of the air by a certain quantity and diminishes correspondingly the power which must be furnished to the fan in order to bring the air to atmospheric pressure.

The measure of the total resistance of the air is made in the experiment room by means of a balance, into the detail of which we can not here enter.

The pressures exerted on each point of the body subjected to the action of the current of air are determined by means of orifices of very small diameter fixed normally to the surface at various points of the body and connected with manometers.

This installation likewise provides for determining, with reduced models of screw propellers, the thrust of the propeller and the power required on the shaft. By means of a small electric motor the propeller is turned in the cylinder of air produced by the fan. It is assumed that by this means the same conditions are realized as though the propeller itself advanced through the air.

The propeller models have a diameter which does not exceed 1 meter (3.28 feet). In a cylinder of air of 2 meters (6.56 feet) diameter the propeller model is thus surrounded by a mass of air sufficiently thick to represent action in an indefinite medium.

3. THE AEROTECHNIC INSTITUTE OF SAINT-CYR.

The Aerotechnic Institute of Saint-Cyr was created by M. Henri Deutsch de la Meurthe, who gave it as a gift to the University of Paris. Its purpose is to follow lines of research, both theoretical and practical, tending to the improvement of the means of aerial locomotion in all its forms, these researches being carried out under conditions as nearly as possible similar to those actually in practice.

In order to realize this program, there was constructed on the level a railway 1,350 meters in length (4,428 feet), on which are operated special cars.

The car for the tests of surfaces and of airplanes is an electric tractor with normal gauge.

The principal characteristics are as follows:

Weight, not equipped, 5 tons.
Length, 6 meters (19.7 feet).
Width, 2 meters (6.56 feet).
Height, 1.10 meters (3. 61 feet).

The current is taken by lateral shoes sliding on conductors placed on either side of the line.

The motor is of 130 horsepower capacity, separately excited. It is geared to two intermediate shafts, upon which are placed pinions which transmit the movement to the forward and rear axles by Renold chains. All the shafts of the motor and axles are provided with roller bearings.

The brake is applied electrically, with a safety provision, by means of shoes at the rear, engaging at the end of the line on a sliding way.

The control is exercised from an operating cab by means of a controller and an adjustable automatic accelerator.

The maximum velocity of the car is about 20 meters (65.6 feet) per second.

The car is furnished with a special mounting providing for registering the following items:

(1) The vertical component force or lift.

(2) The horizontal component force or drift. (These together define the resistance of the air in magnitude.)

(3) A rotating couple, from which, with the preceding, may be derived the location of the resistance considered as a single force.

The relative velocity of the body under trial with relation to the air is determined by measuring the absolute velocity of the car with reference to the ground and adding or subtracting the velocity of the wind according to the direction of the line on which the car runs.

The absolute velocity of the car with reference to the ground is measured by means of a registering speed instrument giving directly the revolutions of an axle. Furthermore, there is installed along the line a system of electric contacts inscribing points of reference on the cylinder of a precision chronograph. This cylinder permits a measurement (to 1/200 second or to 1/10 second) of the time required by the car for traversing a known distance—95.9 meters exactly (314.55 feet).

In order to have the correction due to the wind, measurement is made, at a fixed point on the line where the tests are made, of the magnitude and direction of the wind. The velocity of the wind is measured by an anemocinemographe, which is extremely sensitive (20 millimeters (0.788 inch) for 1 meter (3.28 feet) per second velocity). The direction of the wind is measured by a self-registering wind vane. Furthermore, the correction for the wind can not be made with satisfactory rigor unless the average velocity of the wind is at least equal to 2 meters (6.56 feet) per second.

A car of the same type as the preceding, but more robust, serves for the study of an entire airplane. These experiments, still in an introductory stage, have been carried out on a two-passenger machine of the Blériot type. The characteristics of this monoplane are as follows:

Tail plane (pigeon tail).
Span, 11.10 meters (36 feet).
Length, 9 mèters (29.5 feet).
Surface of the wings, 25.35 square meters (272.8 square feet).
Angle of the chord of the wings with the tail plane, 6°.

The ensemble of this apparatus was studied for three positions of the depth rudder:

(*a*) Rudder in the prolongation of the tail plane.

(*b*) Rudder turned 18° downward with reference to the tail plane.

(*c*) Rudder turned 51° upward with reference to the tail plane.

Experimental speeds 15 to 18 meters (49.2 to 59 feet) per second (54 to 65 kilometers (33.5 to 40.4 miles) per hour).

A special car serves for the study of propellers.

The propellers are full sized. They are mounted on the special car which they serve to propel. This car carries a framework which

makes it possible to carry the propeller at a distance from the car itself and to operate the propeller as though it were placed in an indefinite medium. On the car is an 80-horsepower motor which operates the propeller shaft by means of a transmission similar to that which is found on dirigible balloons.

The axles of the car are free and the speed of the car is due solely to the pull of the propeller. A lever brake is provided which is applied by the operator who rides on the car. This brake is, furthermore, similar to that which is used on the car for testing surfaces. The control of the car is carried out from an operating cab similar to that for the car previously described.

The return of the propeller car is obtained by running the propeller backward at reduced speed in order to avoid undue strain. The pull of the propeller is measured by means of a dynamometer inserted between a movable bar articulated at its base and the fixed framework of the car.

The power absorbed by the propeller is measured in two different ways:

(*a*) By means of a wattmeter registering the electric power required by the motor.

(*b*) By means of a transmission dynamometer registering the couple required to drive the propeller.

These two pieces of apparatus are standardized by means of a Renard brake, which is attached to the shaft in place of the propeller.

The velocity of the car is determined by the same two methods as above noted for investigating surfaces.

The number of revolutions of the propeller is measured by means of a registering counter.

The relative velocity is obtained by making a correction for the wind, the same as in the case for surfaces.

The velocities realized have not exceeded 20 meters (65.6 feet) per second.

The Aerotechnic Institute has undertaken to make a series of tests on airplanes in free flight.

M. Toussaint, assistant director of the institute, has carried out the following investigations:

First, on a Maurice Farman biplane, piloted by Capt. Etévé.

Second, on a Blériot monoplane, piloted by Lieut. Gouin.

The following items of equipment were installed:

(1) A recorder of relative velocity giving the speed of the airplane relative to the air.

(2) A registering wind vane giving the inclination of the wind to the chord of the planes.

(3) A registering clinometer giving the longitudinal inclination of the airplane relative to the horizontal.

(4) A registering barograph, very sensitive up to 500 meters.

(5) A registering revolution counter giving the speed of the engine.

(6) A register of the movement of the depth rudder.

(7) A register of the warping of the planes.

All these registering instruments, except the revolution register, are provided with cylinders of such proportions as to give a length of diagram of 292 millimeters (11.5 inches) in 26 minutes—that is, 11.2 millimeters (0.442 inch) per minute. With this velocity of movement of the record one may judge the periods of steady condi-

tions exceeding 10 to 20 seconds duration. Quantitative measures can not be properly drawn from periods of steady condition having less than this duration.

In order to assure a perfect agreement in time between the different diagrams, or, in other words, in order to be perfectly sure that the points taken as corresponding do indeed relate exactly to the same instant of flight, each register is provided with a supplementary pen moved by an electromagnet. Throughout the course of the flight the pilot by closing the circuit at sufficiently close intervals causes these pens to register simultaneously on all the diagrams.

The reference points thus traced are all in synchronism, and thus provide an assurance of perfect accord for measurements made in the vicinity of these points.

In order to protect the instruments from vibrations and shocks, they are provided with elastic suspension in their cases.

We shall not enter into the details of the description of these various instruments. We note simply that the register for velocity relative to the air, as well as the direction vane, should be placed in such manner as to avoid the turbulence produced by the propeller, the planes, and the body.

The register for the movements of the depth rudder and for the warping of the planes was installed on the Blériot. This gives on one cylinder the movements of the handwheel barrel. It comprises simply a system of axes with tracing points, parallel between themselves and perpendicular to the axis of the registering cylinder. Each one of these axes carries, on the one hand, a lever connected to the barrel by a wire, and, on the other hand, a stylus or marking pen. A return spring fixed on the lever serves constantly to maintain the wire under tension. This wire is attached to the barrel at the same point as the cable which operates the corresponding control; it passes over little pulleys and is thus carried to the register. The movements of the stylus for the position of the barrel corresponding to horizontal flight and to various inclinations of the depth rudder are marked on the register, the axis of the propeller in repose being horizontal. Similarly reference marks are determined in repose for the movements of the stylus registering the warping movements of the planes. In the apparatus of the institute the needle rises when the barrel is carried to the left; it descends when it is carried to the right.

The Aerotechnic Institute possesses also an installation for the study of small models by means of a fan. The fan absorbs 120 horsepower, providing for a flow in an experimental section of 2 meters (6.56 feet) diameter of a current of air of 40 meters (131.2 feet) per second or 144 kilometers (89.4 miles) per hour. The total delivery amounts to 125 cubic meters (4,412 cubic feet) per second. This apparatus is under trial.

There is also at the Institute of Saint-Cyr a covered installation for the study of small models. The diameter of the rotunda is equal to 38 meters (125 feet). The turning arm is about 16 meters (52.5 feet) in length. The velocity at the extremity is 90 to 95 kilometers (56 to 59 miles) per hour.

4. THE LABORATORY OF M. DE GUICHE.

M. de Guiche has instituted a systematic series of experiments by the method of displacing the body under investigation in quiet air.

The body (use so far has been made of plates in various forms) is carried by an automobile. Two vertical pillars fixed to the machine carry at their upper extremities a horizontal axis on which are placed the various plates under investigation. These plates are provided at their lateral extremities with two graduated half circles, which, by means of a needle carried by each pillar, serve to measure their inclination relative to the line of movement. The pillars are of sufficient height and so placed that the turbulence produced by the automobile itself is not felt in their neighborhood. In particular, M. de Guiche has found it advantageous to carry the mounting on the rear of the automobile rather than on the front. The wheels and the body throughout are, furthermore, suitably shielded in order to diminish turbulence.

M. de Guiche thus carries out a sort of topographical measure of the pressures exerted on the different points of the plates both on the front and rear sides.

As we have seen previously, M. Eiffel likewise employs this method, but he determines separately the pressures at the different holes and measures each time the velocity of the current of air by means of a Pitot tube. As this velocity is somewhat variable, the pressures are reduced to what they would be if the velocity were constantly equal to 10 meters (3.28 feet) per second.

But in operating this by successive observations there is danger of finding between the determinations marked discordance.

Therefore, M. de Guiche determines at the same time, and by a single experiment, the pressures at selected points in as large a number as possible. To this end the plates which are to serve for the experiment are pierced, each with holes forming two series of lines cutting each other at right angles (for planes, lines at the maximum slope and horizontal lines). In a single experiment, and at the same instant, the pressures in all these points of the several lines are measured.

To this end, 20 orifices ending at these holes on the various lines are provided with 20 rubber tubes connecting them with 20 little manometers. These manometers are mounted side by side in a frame before a glass provided with transverse divisions in half millimeters.

The indications of all these manometers are inscribed at any given instant by placing them in a photographic chamber where the atmospheric pressure acts upon their open ends. By lighting the interior of the chamber with electric lamps, there is readily produced on a photographic plate the levels of the liquid in the different manometers.

It may be asked if the pressure of the atmosphere actually prevails in the interior of the photographic chamber. The latter can not, in effect, be perfectly tight, if it is not desired that it should operate as an air thermometer. It is then possible that during the movement of the automobile, currents of air passing through small apertures of the photographic chamber may tend to produce a variation of pressure within. M. de Guiche has assured himself by many experi-

ments that this effect is entirely absent and that atmospheric pressure prevails throughout the interior of the photographic chamber.

At the Institute of Saint-Cyr, M. Maurain, who has employed the manometric method, undertook to establish in spite of the perturbations caused by the movement of the vehicle, the atmospheric pressure on the open part of the manometers which he uses for measuring pressure. To this end the open part is connected to a space, completely tight, which communicates with the outside air by means of a tube placed at the extremity of an antenna. The latter is placed quite far from the surface in order to escape variations of pressure which are produced in its vicinity (2.3 meters, 7.54 feet) in front of the surface under investigation and 3.35 meters (10.9 feet) above the body of the car. At the extremity of this antenna is a tube of which the useful part is horizontal and cylindrical and is terminated by a pointed closed cone pointing in the direction of movement. In the cylindrical and lateral part of the tube are formed small circular openings of 1 millimeter (0.04 inch) in diameter which place it in communication with the atmosphere. M. Maurain has assured himself that this tube placed in a current of air of 20 meters (65.6 feet) per second approximately parallel to the current assumes indeed the pressure of the atmosphere.

The pressures thus determined directly are reduced to the values which they would have at a velocity of 10 meters (32.8 feet) per second. Curves of equal pressure may then be traced, thus indicating the condition of the surface of the body and showing the distribution of pressure over the same.

Furthermore, the surface of the body is divided into strips of a certain width. By a calculation of averages, the mean pressure is determined for each strip. Multiplying this by the surface of each strip, we have the resistance exerted by the air on the given strip. As the surface of the body under investigation is perfectly smooth, the friction of the air on such surface may be neglected. The force determined is then normal to the surface of the body. By combining these forces by the well-known methods of graphical statics, the resistance of the air over the entire plate may be obtained in magnitude and location.

Finally, in the experiments of M. de Guiche the automobile should move through a mass of air motionless as a whole. To this end the experiments are made at certain hours on favorable days over a road traversing a forest. The road is about 30 meters (98.4 feet) wide and is bordered with small brush. The straight part in which the measures are taken is determined at its two ends by easy turns. There is thus avoided the establishment of a regular current of air along the axis of the road.

The velocity of the automobile relative to the ground is measured, correcting it, if necessary, for the component of the wind along the direction of motion.

5. THE LABORATORY OF CHALAIS-MEUDON AND THE EXPERIMENTS OF M. LE COMMANDANT DORAND.

The aerotechnic laboratory of Chalais-Meudon is celebrated throughout the entire world by reason of the work of Col. Charles Renard. It is there that were made the studies which have brought the solution of the problem of the dirigibility of balloons. It is there that

have been established by precision experiments some of the fundamental laws of air resistance. It is there, finally, that were made certain experiments by Capt. Ferber, experiments which should soon lead to the French solution of the problem of aviation.

M. le Commandant Dorand has brilliantly continued the labors of these eminent predecessors. The experiments made here on air propellers have carried a long step forward this complex question.

They were made on propellers of normal size by means of the car method, which was later applied at the Institute of Saint-Cyr.

The propeller to be tested is mounted on a car moving on a railroad. This car carries a dynamo shunt excited, by means of which the propeller is turned at a constant speed. On the same car are placed registering apparatus for thrust, speed of car, speed of rotation, and power absorbed.

The railroad, of 1 meter gauge (3.28 feet), on which moves the dynamometer car, has for half of its length a uniform grade. It is prolonged by a level run and then by an ascent, destined to diminish the velocity of the car before application of the automatic brakes. There is utilized in this manner the weight of the equipment, the effect of which added to the propulsive effort of the propeller gives rapidly to the vehicle a high velocity, and brings it back to the point of departure after the experiment. The current intended for the electric motor is brought by two insulated rails, on which move sliding shoes of bronze similar to those which are used for electric railroads.

In order to obtain a constant electric resistance in the circuit, no matter where the car may be on the track, the current is brought to the rails at two opposite extremities. By this means the instruments for the measuring of electric quantities may be located at a fixed point and not on the vehicle.

The energy is transmitted to the propeller shaft by means of a chain.

In order to measure the tractive pull of the propeller there is carried at the end of the propeller shaft (turning in roller bearings) a roller thrust bearing which transmits the tractive effort to a manometric cell. A registering dynamometer thus gives at each instant the thrust of the propeller.

The power absorbed by the propeller is obtained by means of indications furnished by an ammeter and a voltmeter of the recording type, previously standardized for the different speeds of the motor by the aid of a Renard brake.

Chronographs indicating the origin of time are mounted on each of the registering equipments and are put in movement automatically at the same moment.

The part of the apparatus provided for the measuring of the propeller thrust is movable relative to the car. It results that the tractive effort directly measured represents the algebraic sum of the following forces:

(*a*) Tractive effort on the level;

(*b*) $+ph$, p being the weight of the moving system and h the change of level per meter run;

(*c*) Inertia $= -\frac{p}{g}\frac{dv}{dt}$, g being the acceleration due to gravity, and $\frac{dv}{dt}$ the acceleration of the motion of the car.

The tractive effort on the level, which interests us here, is then equal to the tractive effort measured directly, diminished by ph and augmented by $\frac{p}{g}\frac{dv}{dt}$. For an acceleration which remains near 0.8 meter second (2.6 feet per sec.), this last correction is

$$p \times \frac{0.8}{9.81} = 0.0815\ p.$$

As p is always less than 60 kilograms (132 pounds), this correction is about 5 kilograms (11 pounds).

The maximum speed of the dynamometer car has been, in these experiments, equal to 14.6 meters (47.9 feet) per second.

M. le Commandant Dorand made, at the military aerodrome of Villacoublay, numerous trials with a biplane of his construction, and piloted by Labouchère.

This flying laboratory is a biplane with planes stepped toward the front; it is provided with an engine of 60 horsepower, with tractor propeller.

During a horizontal flight the following measures were made:

(a) Thrust of the propeller.
(b) Speed of rotation of the propeller shaft or of the engine.
(c) Speed of the airplane relative to the air.
(d) Angle of incidence of the planes.

The measures are instantaneous. At the desired moment in horizontal flight the pilot presses on a button and thus determines the registration of all the measures to be made.

The frame of the engine is mounted in a dynamometer balance on a shaft carried on roller bearings. The moment of the thrust of the propeller relative to this axis is balanced by that of two hydraulic cells. Recording manometers give the pressure at the cells and thus furnish, through the lever relation, the thrust of the screw itself. The recording drums are set in motion at the instant of start of the airplane; chronograph markers moved electrically indicate on each sheet the precise place where the reading is to be made.

The action of the air on that part of the balance comprising the engine and its supports gives rise to a force which must be added to that which is measured, if it is desired to know the true thrust of the propeller. In order to make this correction, the entire system without the propeller is placed in a current of air. The velocity of this is measured as well as the resistance which it develops.

The measure of the thrust of the propeller gives the resistance of the airplane at any given instant of its horizontal flight.

In order to measure the speed of rotation of the engine, there is mounted on the shaft a cylinder of ebonite covered over half its circumference with a sheet of copper. Two brushes installed in the circuit of an electric chronograph rest on this cylinder. At each revolution of the engine there is an interruption of the current and hence a jog on the chronograph sheet.

The measure of the relative velocity through the air is made by means of a Venturi tube. We may note here that the operation of this apparatus has been made at the Aerotechnic Institute of Saint-Cyr, the subject of a very careful and systematic investigation.

The angle of incidence is obtained by means of a clinometer formed by a pendulum dampened in glycerine. A pointer which moves over a scale indicates at each instant the angle of the chord of the planes with the horizon.

Experiments in gliding flight have also been made with this equipment. They require the knowledge of the gradient of the path during the glide, or the angle of the relative air movement with the horizon. This item is furnished by means of a vane with horizontal axis.

6. THE AVIATION LABORATORY OF VINCENNES AND THE EXPERIMENTS OF CAPT. OLIVE.

The ministry of war has instituted, under the charge of the artillery school at Vincennes, a laboratory which is specially concerned with researches in aviation.

Among the investigations carried out in this laboratory, we should note here the measurements made by Capt. Olive on airplanes of normal dimensions. The principle of the method was as follows:

Let us consider a body rigidly suspended from a trolley which rides on a rectilinear inclined cable. Let us assume that the body possesses a plane of symmetry which also contains the cable. The body under investigation, descending along the cable in such manner that its plane of symmetry is displaced parallel to itself, is subjected, at each instant, to the following forces:

(1) The action of gravity applied at the center of gravity.

(2) The resistance of the air applied at a point which we may designate by ρ.

(3) The force of inertia applied at the center of gravity.

These forces may be decomposed parallel and perpendicular to the cable. The components of the weight are opposed to those of the resistance of the air; those of the force of inertia are parallel to them.

Graphic record is made of the magnitude of the components parallel and perpendicular to the cable. When the system is in a state of rest, the weight acts alone. The mode of recording thus provides for the elimination of the effects due to gravity.

The body under investigation is allowed to descend along the cable, with the trolley, to which it is rigidly attached. At a given moment the acceleration, α, of the system is measured and record is made of the components of the resistance of the air and of the force of inertia.

The acceleration α is measured in the following manner: When a pendulum is mounted on a support which, itself, is given a movement of translation with an accelerated velocity, it tends to place itself at each instant in a position such that the angular deviation from the vertical is connected with the acceleration α by the equation

$$\beta = \frac{\alpha}{g}$$

The angle β is, in general, quite small. This principle has been realized in the following manner:

A car moves on an aerial monorail formed by a cable stretched between two posts. The airplane under investigation is suspended from this car by means of a bar to which it is attached through a

network of wires forming triangles, thus giving the equivalent of a rigid connection in every direction. In order that these wires may remain under tension during the experiment, it is necessary that the weight of the airplane shall be greater than the upward thrust received from the air during the movement.

The bar connecting with the car is attached thereto by means which transmit separately to dynamometer springs, on the one hand, the forces normal to the cable, and, on the other, the forces parallel to the cable. The movements of the springs are recorded on a moving cylinder.

The cable on which the car rolls shows a general inclination in such manner that the movement of the apparatus may be produced by the action of gravity.

The experiment should be carried out in a part of the cable where the inclination is practically constant in order to avoid the need of taking account of the varying components of gravity and of the force of inertia produced by the curvature of the cable.

At Vincennes the cable, which is 155 meters (508 feet) long, is carried by two pillars which are installed, one on the summit of a hill of about 20 meters (65.6 feet) height, the other on the crest of an embankment. The maximum deflection of the cable varies between 1.4 meters (4.6 feet) without load to 5 meters (16.4 feet) for a load of 1,000 kilograms (2,204 pounds) placed at the center, the tension remaining constant. The general slope is 12 per cent. In the experiments the weight carried was 700 kilograms (1,543 pounds) and the maximum velocity realized was 12 meters per second (39.4 feet per second).

7. THE EXPERIMENTS OF COMMANDANT LAFAY AT THE PHYSICAL LABORATORY OF THE POLYTECHNIC SCHOOL.

Commandant Lafay has installed in the physical laboratory of the Polytechnic School the apparatus previously used by M. Rateau. He has utilized this apparatus in order to solve, often in an elegant manner, a series of interesting problems in aerodynamics. For example, he has proposed to make visible the paths of air stream lines which surround solid bodies of different forms placed within a cylinder of air issuing from the discharge orifice of a fan.

The methods which give the total resistance of the air enable us generally to determine separately the lift and the drift. From these we may then find the ratio of support, which is nothing but the ratio of the lift to the drift. As a matter of fact, in a horizontal flight, the smaller this ratio, the greater the weight carried by a given effort of propulsion. If we call ϕ the angle of the lift with the total resistance, the relation of the drift to the lift is equal to tang. ϕ. By reason of the importance of this angle, which Commandant Raibaud of the aviation laboratory at Vincennes proposed to call the angle of support, M. Lafay has constructed an apparatus by which it can be determined directly without going through the determinations of the lift and drift.

He has operated on different stuffed birds and has tried to determine the value of this ratio of support for these birds.

He has been brought to the conclusion that a stuffed bird behaves, on the whole, as a mediocre flyer, certainly inferior to one of our good monoplanes.

These experiments which have dealt with stuffed birds can not, with certainty, be extended to living birds. However, this result leads us to admit only with reserve the statements of those who claim that birds are perfect flyers, presenting for the angles of attack which they utilize ratios of support far superior to those of our apparatus.

M. Lafay has set himself another problem which is very important in regard to the practice of aviation.

The experiments made with models of wings or of airplanes are, as a general rule, exclusively static. The wind of the blowing apparatus whose action is utilized is maintained in a constant state during the period of each observation. Now, when an airplane moves through the air it is subject on the part of the air to actions which vary quite rapidly not only in intensity, but also in direction. Although the inertia of an airplane prevents it from obeying all these instantaneous forces, it may be questioned if the static experiments of the laboratory can be applied without restriction to machines in practice. M. Lafay has striven to give a few indications regarding this question. He has tried a few dynamic experiments, i. e., he has tried to study the variable forces produced by a wind which changes rapidly its direction or its intensity.

The experimental study of this problem presents great difficulties, due chiefly to the disturbing actions of inertia. In order to avoid them, he was led to build models as light as possible, attached to elastic carriers, and to make use of the deformations of these carriers in order to measure the forces. But if these deformations are to be very slight, in order that the energy acquired by the system be negligible, they must, however, be sufficiently great and sufficiently regular to permit of arriving, by means of an appropriate optical amplification, at a correct evaluation of the forces which produce them. The results of this amplification must be such that they can be registered photographically on account of the rapidity of evolution in the phenomena under investigation. Finally, the model and its elastic support would not fail to take on a vibratory movement under the action of the inevitable irregularities of the blowing apparatus, except for the precaution of adding just enough dampening to make the apparatus practically aperiodic, without, however, retarding too much its dynamic indications.

M. Lafay has produced an aerodynamometer capable of satisfying these contradictory conditions.

These experiments have been interrupted by the war. However, from those which have been made it seems to be proven that for changes of speed and direction having the degree of rapidity of those which may normally take place in aviation, the resistance of the air at a given moment has a value little different (10 per cent at the most) from that which one would obtain in permanent régime, keeping invariable the conditions which characterize, at the instant under consideration, the movement of the avion relative to the air.

Consequently, we can deduce from static experiments, properly directed, the elements which are necessary for the calculation of the forces sustained by a machine in given circumstances, as, for example, those which accompany its rapid righting after a diving flight, or its entrance into an ascending or descending current of air.

8. AERODYNAMIC STUDIES PERFORMED IN OTHER LABORATORIES.

A certain number of aerodynamic experiments have been made in other laboratories.

Mention may be made of the experiments on propellers at a fixed point performed by M. Auclair in the experimental laboratory of the Conservatoire des Arts et Métiers. This young savant was the first to give precise results on the influence of the back of the blades, an influence which had been noted as early as 1900 by M. Rateau.

L'Institute Marey, in the Parc des Princes, is continuing the fine studies of Marey on the flight of birds.

M. Houssaye, in his laboratory of L'Ecole Normale Supérieure, at Paris, is studying the resistance of water on the forms of fishes.

M. Magnan, in the laboratory of l'Ecole des Hautes Etudes at the Sorbonne, is trying to deduce from the study of the dimensions of birds some coefficients which will be useful for the construction of airplanes.

CHAPTER III.

DIAGRAMS REPRESENTING THE RESULTS OF EXPERIMENTS.

1. PROPOSED NOTATIONS.

Let us consider a reduced size model of the body under investigation. Let λ be the ratio of the homologous linear dimensions taken in the body and in the model.

Let us suppose that the model is tried at a relative velocity V and that the results of the experiments are reduced to what they would be for a velocity V_1. If rv_1 and rv are the actions of the air on the model at speeds V_1 and V, we have the relation

$$\frac{rv_1}{rv}=\left(\frac{V_1}{V}\right)^2 \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

On the other hand, let us take the body under investigation. Let V be its velocity relative to the air, and suppose that the actions of the air are reduced to what they would be if the velocity had the value V_2. Denote by Rv and Rv_2 these values of the resistance of the air. We have the relation

$$\frac{Rv_2}{Rv}=\left(\frac{V_2}{V}\right)^2 \quad . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

The relations (1) and (2) give:

$$\frac{Rv^2}{Rv}\times\frac{rv}{rv_1}=\left(\frac{V_2}{V_1}\right)^2 \quad . \; . \; . \; . \; . \; . \; . \; . \quad (3)$$

But since rv and Rv are relative to the model and to the body under investigation at the same speed V, we have

$$\frac{rv}{Rv}=\frac{1}{\lambda^2} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (4)$$

Carrying this value into (3) we have

$$\frac{Rv_2}{rv_1}=\lambda^2\left(\frac{V^2}{V^1}\right)^2 \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (5)$$

In experiments in aerodynamics the values usually taken are $V_1=V_2=10$ meters per second (32.8 feet per second). Measure is then taken of rv on the model or Rv on a body of normal size. Equations (1) and (2) then give

$$r_{10}=rv\left(\frac{10}{V}\right)^2 \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (6)$$

$$R_{10}=Rv\left(\frac{10}{V}\right)^2 \quad . \; . \; . \; . \; . \; . \; . \; . \quad (7)$$

The methods for the measurement of rv give at the same time:

(a) The component of rv along the direction of relative air movement.

(b) The component of rv normal to the direction of relative air movement.

With M. Eiffel, let us call r_x and r_y, F_x and F_y the components of r_{10} and R_{10} along and normal to the direction of relative air movement, respectively.

We have then the relations:

$$r_x = \text{component of } rv \text{ along direction of relative air movement} \times \left(\frac{10}{V}\right)^2 \quad . \quad . \quad . \quad (8)$$

$$r_y = \text{component of } rv \text{ along normal to direction of relative air movement} \times \left(\frac{10}{V}\right)^2 \quad . \quad . \quad . \quad (9)$$

$$F_x = \text{component of } Rv \text{ along direction of relative air movement} \times \left(\frac{10}{V}\right)^2 \quad . \quad . \quad . \quad (10)$$

$$F_y = \text{component of } Rv \text{ along normal to direction of relative air movement} \times \left(\frac{1}{V}\right)^2 \quad . \quad . \quad . \quad (11)$$

We may note that $r_x\ V^2$, $r_y\ V^2$, $F_x\ V^2$ and $F_y\ V^2$ are quantities of the order of force.

M. Eiffel, in his experiments on models of airplanes, takes $V_2 = 1$ met./sec. = 3.28 ft./sec. and $V_1 = 10$ met./sec. = 32.8 ft./sec.

Equation (5) then gives

$$\frac{R_1}{r_{10}} = \left(\frac{\lambda}{10}\right)^2 \quad . \quad . \quad . \quad (12)$$

M. Eiffel calls R_x and R_y the components of R_1 along and normal to the direction of relative air movement.

We have then

$$\left.\begin{aligned} R_x &= r_x\left(\frac{\lambda}{10}\right)^2 \\ R_y &= r_y\left(\frac{\lambda}{10}\right)^2 \end{aligned}\right\} \quad . \quad . \quad . \quad (13)$$

R_x and R_y are quantities of the same order as r_x and r_y.

If the model of the airplane is on a scale 1/10, $\lambda = 10$ and we have

$$\left.\begin{aligned} R_x &= r_x \\ R_y &= r_y \end{aligned}\right\} \quad . \quad . \quad . \quad (14)$$

The numerical values calculated for the model apply directly to the airplane of normal size.

When the problem involves the wings of airplanes, M. Eiffel places

$$\left.\begin{aligned} K_x &= \frac{\text{component of } r_v \text{ along direction of relative air movement.}}{SV^2} = \frac{r_x}{S \times 10^3} \\ K_y &= \frac{\text{component of } r_y \text{ along normal to direction of relative air movement.}}{SV^2} = \frac{r_y}{S \times 10^3} \end{aligned}\right\} \quad (15)$$

$$K_i = \sqrt{K_x^2 + K_y^2} \quad \ldots\ldots\ldots\ldots \quad (16)$$

In this equation i is the angle between the direction of relative air movement and a reference line attached to the wing, generally the chord of the profile of the wing in its plane of symmetry.

K_x, K_y, K_i are quantities of the order of density.

S should be a mean between the surface of the wing exposed directly to the action of the air and the surface on the back. Builders of airplanes usually consider S equal to the greatest projection of the wing on a horizontal plane.

2. STUDY OF THE WINGS OF AN AIRPLANE—POLAR DIAGRAMS OF M. EIFFEL.

M. Eiffel represents the properties of the wings of an airplane by means of what he calls simple polar diagrams.

On two rectangular axes, he plots as abscissæ the values of K_x and as ordinates the values of K_y, the same scale being used for both. The curve thus traced in the K_x K_y plane is called the "first simple polar." A point of the curve corresponds to a determinate value of the angle i. The radius vector from the origin to this point represents the quantity K_i. The angle of this radius vector with the axis of K_y is the angle between the resistance of the air and the normal to the direction of relative air movement. If this angle is denoted by θ we have

$$\text{tang. } \theta = \frac{K_x}{K_y} \quad \ldots\ldots\ldots\ldots \quad (17)$$

The tangent drawn from the origin to the polar gives the value of θ, θ_m, for which the ratio $\frac{K_x}{K_y}$ is a minimum.

To each point of the curve corresponds a value of the angle i and a value of the angle θ. If $\theta = i$ the resistance of the air is normal to the chord of the profile; if $\theta < i$, the resistance of the air is forward of the normal to the chord. For $\theta > i$ it falls behind the chord.

This mode of representation (K_x and K_y represented to the same scale) is not suitable for the values of the angle i corresponding to the small values employed in aviation. In fact, for these values of the angle i the polar diagram approaches very close to a straight line slightly inclined to the axis of K_y. The comparison of one

wing with another by simple superposition of diagrams is a delicate operation. In particular it is almost impossible to compare the wings regarding the minimum value of $\frac{K_x}{K_y}$.

Accordingly, M. Eiffel constructs what he calls the "second simple polar." He takes for K_x a scale five times larger than for K_y. In this mode of representation, a vector joining the origin with a point on the curve is no longer equal to K_t, and the angle of this vector with the axis of K_y is no longer the angle θ. However, the same as for the small values of i, less than 10°, K_t is very little different from K_y, and for the values K_t the ordinates of the new curve may be taken. It is convenient to add to this curve a scale representing values of $\frac{K_x}{K_y}$. On a parallel to the axis of K_x, passing through a point of K_y, values are plotted of $\frac{K_x}{K_y}$ corresponding to one of the intersections with the new curve of the radius vector starting from the origin and ending at this point. Let us call this line the axis of $\frac{K_x}{K_y}$. In order that $\frac{K_x}{K_y}$ may correspond to an angle i, it is necessary that the vector just named should cut the second polar curve. The minimum value of $\frac{K_x}{K_y}$ is then given by the point where the tangent from the origin to the polar curve meets the axis of $\frac{K_x}{K_y}$.

3. STUDY OF THE HORIZONTAL MOVEMENT OF AN AIRPLANE—THE LOGARITHMIC POLAR CURVE.

In order to study the horizontal movement of an airplane, M. Eiffel has pointed out a very ingenious representation, to which he has given the name of logarithmic polar.

Let us consider a model of an airplane and let i be the angle made between the direction of relative air movement and a straight reference line intimately connected with the apparatus, for example, a straight line doubly tangent to the lower part of the principal planes, near the fuselage. To this value of the angle i, the experiment on the model will give corresponding values of the resistance of the air, of which the projections parallel and perpendicular to the air movement are r_x and r_y. To these, equations (13) serve to give the corresponding values of R_x and R_y relative to an airplane of full size.

Furthermore, let

Q = the weight of the actual airplane.

P = the power required to maintain horizontal flight with a relative velocity V.

The equations

$$\left.\begin{array}{l} P=R_xV^3 \\ Q=R_yV^2 \end{array}\right\} \quad \ldots\ldots\ldots\ldots \quad (18)$$

define the correlative values of P, Q, V, R_x and R_y, and hence of the angle i which corresponds to the horizontal flight of an airplane of determinate form (especially of an airplane in which the depth rudder

occupies a determinate position) when the axis of the propeller is parallel to the path of flight.

Let us consider such an airplane.

Equations (18) give immediately

$$\left.\begin{array}{l}\log. R_x = \log. P - 3 \log. V \\ \log. R_y = \log. Q - 2 \log. V\end{array}\right\} \quad \ldots\ldots\ldots \quad (19)$$

or

$$\left.\begin{array}{l}\log. R_x = \log. P - \dfrac{3}{\sqrt{13}} \times \sqrt{13} \log. V \\[2ex] \log. R_y = \log. Q - \dfrac{2}{\sqrt{13}} \times \sqrt{13} \log. V\end{array}\right\} \quad \ldots\ldots \quad (20)$$

The experiments on a model permit, for various values of i, the determination of corresponding values of R_x and R_y.

On two rectangular axes let us plot to the same scale, on the axis of abscissæ, distances proportional to the various values of log. R_x; on the axis of ordinates, distances proportional to the various values of log. R_y. We shall thus obtain in the plane of the axes a curve to which M. Eiffel has given the name of logarithmic polar. Each point on this curve corresponds to a determinate value of the angle i which is inscribed on the curve.

Let us consider a vector OM_i running from the origin O to a point M_i on the curve. This vector has for projections on the axes of coordinates the values log. R_x and log. R_y. But equations (20) show that this vector is the resultant of a broken line of which the vectors are

log. P directed along the axis of log. R_x.
log. Q directed along the axis of log. R_y.

$\sqrt{13} \times$ log. V directed in the third angle of the coordinate planes (−log. R_x, — log. R_y), and making with the axis of log. R_x an angle of which the cosine is equal to

$$-\frac{3}{\sqrt{13}} \text{ (See fig. 1.)}$$

If the two extremities, O and M_i, of the broken line are preserved, the segments may be run through in any order whatever. Thus, for example, we may have any one of the following orders:

log. P, $\sqrt{13} \times$ log. V, log. Q;
log. Q, log. P, $\sqrt{13} \times$ log. V;
$\sqrt{13} \times$ log. V, log. Q, log. P.

It is well known that starting from the point O one should, following the broken line, end at a point M_i of the logarithmic polar. The directions of the vectors are, furthermore, well known. If we take two of the vectors of the broken line, the trace of this line permits immediately the determination of the third.

We may thus solve graphically by means of the logarithmic polar a series of problems relating to the horizontal flight of an airplane

when the axis of the propeller is parallel to the path. We might, for example, desire to know what weight should be given to the apparatus in order to obtain a given velocity with a given power.

In this problem the vectors log. P and $\sqrt{13} \times$ log. V are known in magnitude and direction; it is easy to trace them. From the extremity of the vector $\sqrt{13} \times$ log. V there is drawn a straight line parallel to the axis of log. R_y, which is continued to its point of intersection with the logarithmic polar. The vector log. Q is thus constructed; it gives the weight Q which is sought. At the same time, the point of intersection of this vector with the polar curve determines the angle i of the flight.

Let us now consider a velocity V_o which is, for example, the normal actual velocity of the airplanes (100 kilometers (62.1 miles) per hour). Then equations (18) may be written

$$\left.\begin{aligned}\frac{P}{V_o^3}&=R_x\left(\frac{V}{V_o}\right)^3\\ \frac{Q}{V_o^2}&=R_y\left(\frac{V}{V_o}\right)^2\end{aligned}\right\}\qquad(21)$$

From these we derive

$$\left.\begin{aligned}\log. R_x&=\log.\left(\frac{P}{V_o^3}\right)-\frac{3}{\sqrt{13}}\sqrt{13}\times\log.\frac{V}{V_o}\\ \log. R_y&=\log.\left(\frac{Q}{V_o^2}\right)-\frac{2}{\sqrt{13}}\sqrt{13}\times\log.\frac{V}{V_o}\end{aligned}\right\}\qquad(22)$$

On the axis log. V let us take a point V_o such that

$$OV_o=\sqrt{13}\times\log. V_o\quad\text{(fig. 1.)}$$

The vector V_oV then represents

$$\sqrt{13}\times\log.\frac{V}{V_o}.$$

Let us then carry this vector over to C_oB on the vector AB, and then project C_o to A_o on the axis log. R_x. Finally, lead the vector A_oB_o to the ordinate parallel to the axis log. R_y. To the contour $OABM_i$, in which

$$OA=\log. P,\ AB=\sqrt{13}\times\log. V,\ BM_i=\log. Q,$$

we thus substitute the contour $OA_oB_oM_i$, which is its equivalent since it has the same resultant, and which is such that

$$OA_o=\log.\left(\frac{P}{V_o^3}\right),\ A_oB_o=\sqrt{13}\times\log.\frac{V}{V_o},\ B_oM_i=\log.\left(\frac{Q}{V_o^2}\right)$$

We have as a result:

$$\begin{aligned}&\text{Vector } OA_o=\text{vector } OA+\text{vector } AA_o\\ &\text{Vector } AA_o=-3\log. V_o\\ &\text{Vector } OA_o=\log. P-3\log. V_o=\log.\left(\frac{P}{V_o^3}\right)\end{aligned}$$

As we shall have constantly to consider a vector $V_o V$ or $A_o B_o$ or $\sqrt{13}\times\log.\frac{V}{V_o}$, it is natural to carry the point V_o to the origin.

When the velocity of the airplane is equal to V_o, the vector $A_o B_o$ disappears; the points A_o and B_o become coincident with the point M_x (fig. 2). It is, in fact, easy to see that we have

$$M_x A_o = 3\log.\frac{V}{V_o},\ B_o M_x = 2\log.\frac{V}{V_o}$$

The coordinates log. R_x and log. R_y of the point have then for values

$$\left.\begin{aligned}\log. R_x &= \log.\left(\frac{P_o}{V_o^3}\right)\\ \log. R_y &= \log.\left(\frac{Q_o}{V_o^2}\right)\end{aligned}\right\} \qquad (23)$$

From these equations we derive

$$\left.\begin{aligned}R_x &= \frac{P_o}{V_o^3}\\ R_y &= \frac{Q_o}{V_o^2}\end{aligned}\right\} \qquad (24)$$

We are therefore able to develop a correspondence between a point M_x on the axis of abscissæ (fig. 1) and a value R_x, such that

$$OM_x = \log. R_x,$$

and a value P_o of the useful power such that

$$OM_x = \log.\left(\frac{P_o}{V_o^3}\right)$$

In other words, the axis of abscissæ may be graduated in terms of useful power.

In the same way we may graduate the axis of ordinates in terms of weight.

Let us now suppose that, in a problem, we have given the useful power P and the speed V. The axis of abscissæ, which is the scale for P, gives immediately the point A_o, such that

$$V_o A_o = \log.\left(\frac{P}{V_o^3}\right) \quad \text{(See fig. 2.)}$$

The vector $V_o V$ is such that

$$V_o V = \sqrt{13}\times\log.\frac{V}{V_o}.$$

The contour $V_o A_o B_o$ may be traced. By carrying $B_o M_t$ parallel to log. R_y and extending to the point of intersection with the polar curve, there is found the vector

$$B_o M_t = \log.\left(\frac{Q}{V_o}\right).$$

If this vector is led down from V_0 on the scale of R_y, which is at the same time the scale of weight, the extremity of the segment gives immediately the weight Q which is sought.

In the system of units (meter, kilogram, second) generally used, P is expressed in kilometer-seconds, V in meter-seconds, Q in kilograms (weight). It is more convenient, for practical application, to graduate the scales for P and V in horsepower and in kilometers per hour. To this end it is sufficient to divide the indications of the first scale by 75 for horsepower and to multiply by 3.6 the numbers relating to velocity.

If the velocity W is less than V_0, the segment is directed opposite to the segment V_0V. The contour to consider is $V_0\ A_0'\ B_0'\ M_t$. (See fig. 2.) We have, in fact, in this case

$$\left.\begin{aligned}\log. R_x &= \log. \left(\frac{P}{V_0^3}\right) + 3 \log. \frac{V_0}{W}\\ \log. R_y &= \log. \left(\frac{Q}{V_0^2}\right) + 2 \log. \frac{V_0}{W}\end{aligned}\right\}$$

It is easily seen that these equations represent the projections on the two axes of the contour $V_0\ A_0'\ B_0'\ M_t$.

We are thus led to the following rule:

If we follow a broken line starting from the origin and ending on the polar curve, the direction in which each vector is traversed is the direction in which such vector should be placed, starting from the origin, on the corresponding scale in order to give its value.

It results immediately that if we have the contour V_0ABCD (fig. 2), the vector BC corresponds to a speed greater than the vector BD, these two speeds being, furthermore, inferior to V_0.

Let us suppose, now, that the results found with the model do not correspond to the conditions which had been fixed *a priori* for the airplane. The question may then arise of changing proportionately the dimensions of the apparatus.

Let N be the ratio of the lineal dimensions of the second apparatus to those of the first; N, for example, might be 1.10 for an increase of 10 per cent in the dimensions.

The fundamental equations of horizontal flight for this new apparatus will be

$$\left.\begin{aligned}\frac{P}{V_0^3} &= R_x N^2 \left(\frac{V}{V_0}\right)^3\\ \frac{Q}{V_0^2} &= R_y N^2 \left(\frac{V}{V_0}\right)^2\end{aligned}\right\} \quad \ldots\ldots\ldots\ldots \quad (25)$$

It is not necessary to construct special polar curves corresponding to various values of N in order to determine the value suited to this number. We find, in fact, from equations (25)

$$\left.\begin{aligned}\log. R_x &= \log. \left(\frac{P}{V_0^3}\right) - 3 \log. \frac{V}{V_0} - 2 \log. N\\ \log. R_y &= \log. \left(\frac{Q}{V_0^2}\right) - 2 \log. \frac{V}{V_0} - 2 \log. N\end{aligned}\right\} \quad \ldots\ldots \quad (26)$$

To the vectors,

$$\log.\left(\frac{P}{V_0^3}\right),\ \log.\left(\frac{Q}{V_0^3}\right),\ \sqrt{13}\times\log.\frac{V}{V_0},$$

it is convenient to add a fourth vector,

$$\sqrt{8}\times\log. N.$$

This is directed along the line making the angle $5\frac{\pi}{4}$ with the axis abscissæ (Axis V_0 N, fig. 2).

If N is greater than unity, the values of log. N are laid off along this axis; if N is less than unity, they are laid off along the line $\frac{\pi}{4}$ with the axis of the abscissæ.

If then the values fixed in advance are P, Q, V, it is sufficient, in order to have the value of N which will permit of realizing these values, to draw the fourth segment in a suitable direction until it meets the polar curve. The fourth segment indicates, furthermore, by its intersection with the polar curve, a suitable angle of flight.

Instead of terminating the polygonal contour running from the origin to a point of the curve by the vector $\sqrt{8}\times$ log. N, we may trace this segment first. In other words, instead of starting from the origin of coordinates as the origin of contour, we may start from a point situated on the axis of N. We then see immediately by the figure what becomes of the properties of an airplane, for which the dimensions have been multiplied by the number determined by the point on the axis of N which was taken for the point of departure. Every broken line drawn between this point and the polar curve gives the system of values P, Q, V, which corresponds to the modified apparatus.

We can not here indicate the solution of all the problems for which the consideration of the logarithmic polar provides. To this end, reference should be made to the work of M. Eiffel noted in the bibliography attached to this paper. However, we may note, in résumé, the results to which this study of the logarithmic polar leads.

For all the forms of apparatus studied by M. Eiffel, the logarithmic polar curves always present the same general characteristic, that of figure 3. Beginning with small values of the angles of incidence, we find the angles of horizontal flight for which the properties are the following:

(1) Angle i_1 for which R_x is minimum (fig. 3).

This angle is given by the point of contact of the tangent to the polar, parallel to the axis of ordinates.

Horizontal flight under this angle corresponds to the maximum speed for a given power, or to the minimum power for a given speed.

(2) Angle i_2 for which $\frac{R_x}{R_y}$ is a minimum (fig. 3).

This angle is given by the point of contact of the tangent to the polar curve, drawn parallel to the axis of N.

Horizontal flight under this angle corresponds to the minimum tractive force required for a given weight, or to the maximum weight for a given tractive force.

(3) Angle i_3 for which $\frac{R_x^2}{R_y^3}$ is a minimum (fig. 3).

This angle is given by the point of contact of the tangent to the polar curve, drawn parallel to the axis $V_0 V$.

Horizontal flight under this angle corresponds to the minimum power for a given weight, or to the maximum weight for a given power.

(4) Angle i_4 for which R_y is maximum (fig. 3).

This angle is given by the point of contact of the tangent to the polar curve, drawn parallel to the axis of abscissæ.

Horizontal flight under this angle corresponds to the maximum weight for a given speed, or to the minimum speed for a given weight.

It is seen that to each one of the angles of incidence, i_1, i_2, i_3, i_4, we may relate two magnitudes, of which one is maximum or minimum when the other is given. Each one of these angles is the most favorable angle regarding the two corresponding magnitudes.

As these polar curves, in their useful part, do not have a point of inflection, it follows that the nearer the angle of horizontal flight lies to one of the angles i_1, i_2, i_3, i_4, the better are the conditions with regard to the group of magnitudes which correspond to these angles.

Let us take an example. The weight carried by an airplane is judged to be too small. It is desired to gain weight at the expense of speed, but at the same time preserving the same expenditure of power. It is sufficient to approach the point for which the weight will be maximum for a given power. It is well to give to the apparatus a construction such that horizontal flight (with the axis of the propeller in the direction of the path) is made under an angle as near as possible to the values indicated for i_3.

We have constructed the logarithmic polar curve for a given position of the depth rudder. We have, by means of this curve, studied the properties of horizontal flight for an apparatus under different angles of flight. We have then supposed that for all these angles the air resistance passed sensibly through the point of intersection of the axis of the propeller and of the vertical through the center of gravity. For each apparatus this is sensibly true for an average position for the depth rudder.

But we may approach still more closely to reality. Experiments made on a model with various positions of the depth rudder give the resultants of the air resistance which pass exactly through the point γ of intersection of the axis of the propeller and of the vertical through the center of gravity. We then have sufficient data for the following tables:

Position of rudder.	Characteristics of the resistance of the air, passing through Γ:
A	R_xA, R_yA, iA
B	R_xB, R_yB, iB
C	R_xC, R_yC, iC

With these data we may construct the curves

$R_y = f_1\ (R_x)$ Ordinary polar curve.
$R_y = f_2\ (i)$
log. $R_y = f_3$ (log. R_x) Logarithmic polar curve.

A point of one of these curves gives, not only the values of R_x, R_y, i, but indicates at the same time the corresponding position of the depth rudder.

4. THE CHARACTERISTIC COEFFICIENTS OF PROPELLERS ACCORDING TO G. EIFFEL.

The experimental study of the propeller includes the following quantities:

(1) The thrust, Π.

(2) The effective power, P_e, delivered to the propeller shaft.

(3) The number n of revolutions per minute of time.

(4) The velocity of flight, V.

These experimental data permit the determination of the following:

(*a*) The useful power expended in propulsion

$$P_u = \mathrm{w} \times V \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (27)$$

(*b*) The angular velocity, $2\pi n$. The speed of rotation of the extremity of the blade of the propeller πnD (D equals the diameter of the propeller)

(*c*) The moment of the couple of rotation

$$C = \frac{P_e}{2\pi n} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (28)$$

(*d*) The efficiency of the propeller

$$\rho = \frac{P_u}{P_e} = \frac{\Pi}{C} \times \frac{V}{2\pi n} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (29)$$

What are then the coefficients which should be considered in the study of a propeller?

(1) The direction of the relative velocity at the extremity of a blade; it is characterized by the ratio

$$\frac{V}{\pi nD}$$

(2) Magnitudes of the nature of a density,

$$\frac{\Pi}{n^2D^4}, \quad \frac{C}{n^2D^5}, \quad \frac{P_e}{n^3D^5}, \quad \frac{P_u}{n^3D^5} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (G_1)$$

(3) The abstract number ρ.

Let us assume, as a first approximation, that the magnitudes here mentioned are functions of a single ratio $\frac{V}{nD}$.

It is naturally the same with the magnitudes.

$$\frac{\Pi}{n^2D^4}\left(\frac{V}{nD}\right)^m; \quad \frac{C}{n^2D^5}\left(\frac{V}{nD}\right)^p; \quad \frac{P_e}{n^3D^5}\left(\frac{V}{nD}\right)^q; \quad \frac{P_u}{n^3D^5}\left(\frac{V}{nD}\right)^{q'};$$

whatever may be the exponents m, p, q, q'.

In the group (G_1) the velocity V does not enter. We may then dispose the preceding exponents in such manner as to define two other groups of coefficients which do not contain D or n.

By taking $m = -4$, $p = q = q'$, $= -5$, we have the group (G_2)

$$\frac{\Pi n^2}{V^4}, \quad \frac{Cn^3}{V^5}, \quad \frac{P_e n^2}{V^5}, \quad \frac{P_u n^2}{V^5} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (G_2)$$

By taking $m = p = -2$, $q = q' = -3$, we derive the coefficients

$$\frac{\Pi}{D^2V^2}, \quad \frac{C}{D^3V^2}, \quad \frac{P_e}{D^2V^3}, \quad \frac{P_u}{D^2V^3}, \quad . \quad . \quad . \quad . \quad . \quad . \quad (G_3)$$

With the efficiency ρ, the preceding groups define 13 coefficients which may serve to characterize a problem.

Among these coefficients it is sufficient to note more especially the following:

$$\frac{P_e n^2}{V^5}, \quad \frac{P_e}{D^2 V^3}, \quad \rho \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (G_4)$$

Two problems, in fact, often arise, as under (1) and (2) following.

(1) Suppose an airplane for which we must choose a propeller directly connected with the motor.

We have given, the speed of translation, V, of the airplane, the power, P_e, and the number of revolutions, n, of the engine. These data enable us to calculate the coefficient $\frac{P_e n^2}{V^5}$.

What is the diameter which should be given the propeller?

What is the efficiency of this propeller under the preceding conditions of operation?

Let us take a given type of propeller. Suppose a study of a model of this propeller has permitted us to construct curves giving as a function of $\frac{V}{nD}$ the various values of $\frac{P_e n^2}{V^5}$ and of ρ.

It is then easy to take from one of these curves the value of $\frac{V}{nD}$ which corresponds to the particular value of $\frac{P_e n^2}{V^5}$ suited to the propeller. This value of $\frac{V}{nD}$ gives immediately the diameter of the propeller as desired.

At the same time, on the other curve corresponding to the value of $\frac{V}{nD}$ thus determined, we may read the value of the efficiency ρ.

(2) Suppose an airplane with chain-connected propeller or a dirigible.

We have given the power, P_e, of the engine, the speed of translation, V, the diameter of the propeller, D, and, in consequence, the coefficient $\frac{P_e}{D^2 V^3}$.

It is required to determine the number of revolutions of the propeller and its efficiency.

Let us suppose that for a given type of propeller we have, by means of model experiments, constructed curves giving as a function of $\frac{V}{nD}$ values of $\frac{P_e}{D^2 V^3}$ and of the efficiency ρ.

On the first curve the particular value calculated for $\frac{P_e}{D^2 V^3}$ gives the corresponding value of $\frac{V}{nD}$, and, in consequence, the number of revolutions, n, of the propeller. To this value of $\frac{V}{nD}$ there corresponds a value of the efficiency ρ which is read on the second curve of efficiencies.

What has been said shows that the construction of two curves relating to two coefficients of the groups (G_1), (G_2), (G_3) (the efficiency ρ being joined to each one of these groups) suffices for the determination for the operation of a propeller under determinate conditions. We may represent as a function of $\frac{V}{nD}$ the following:

$$\frac{\Pi}{n^2D^4} \text{ and } \frac{C}{n^2D^5} \text{ of the group } (G_1),$$

$$\frac{\Pi\, n^2}{V^4} \text{ and } \frac{Cn^3}{V^5} \text{ of the group } (G_2),$$

$$\frac{P_e}{n^3D^5} \text{ and } \frac{P_u}{n^3D^5} \text{ of the group } (G_1),$$

etc.

We may indeed construct but a single curve, that which corresponds to the power P_e, for example, on the condition of noting on such curve the various values of the efficiency.

We have assumed, as a first approximation, that any coefficient Γ of one of the preceding groups is represented by a single curve in the plane $\left(\Gamma, \frac{V}{nD}\right)$.

In reality, to each value of $\frac{V}{nD}$ there correspond in the plane $\left(\Gamma, \frac{V}{nD}\right)$ various values of Γ. These latter correspond to varying values of nD or of $\pi\, nD$ (velocity of rotation at the extremity of the blade). Instead of having for Γ a single representative curve in the plane $\left(\Gamma, \frac{V}{nD}\right)$, there are several curves, of which each one corresponds to a particular value of nD.

However, for values of nD varying by 10 units (D expressed in meters, n in revolutions per second) in the field of values of nD comprised between 25 and 50 (values actually met with in practice), the curves corresponding to the various values of nD differ but little from an average curve, which is the one here considered.

5. STUDY OF THE PROPERTIES OF PROPELLERS—THE LOGARITHMIC DIAGRAM OF M. EIFFEL.

We have now to consider the representation as a function of $\frac{V}{nD}$ of the coefficients $\frac{P_e}{n^3D^5}$ and $\frac{P_u}{n^3D^5}$.

We develop this representation by taking for abscissæ values of log. $\frac{V}{nD}$ and for ordinates values for log. $\frac{P_e}{n^3D^5}$ and log. $\frac{P_u}{n^3D^5}$ (fig. 4).

We thus obtain what M. Eiffel calls the logarithmic diagram for propellers.

When these diagrams are constructed we may read directly, by means of a single scale and from axes suitably chosen, the values of the 13 coefficients, ρ and the groups (G_1), (G_2), (G_3).

These same diagrams give us also directly the various values of the magnitudes

$$V,\ n,\ D,\ \Pi,\ C,\ P_e,\ P_u,\ \rho.$$

Let us now show how, by means of these diagrams, the values of the 13 characteristic coefficients of a propeller may be read. We have the following relations:

$$\left.\begin{array}{l}
\log. \dfrac{\Pi}{n^2D^4} = \log. \left[\dfrac{\Pi V}{n^3D^5} \times \dfrac{nD}{V}\right] = \log. \dfrac{P_u}{n^3D^5} - \log. \dfrac{V}{nD} \\[2ex]
\log. \dfrac{C}{n^2D^5} = \log. \left[\dfrac{2\pi nC}{n^3D^5} \times \dfrac{1}{2\pi}\right] = \log. \dfrac{P_e}{n^3D^5} - \log. 2\pi \\[2ex]
\log. \rho = \log. \dfrac{P_u}{P_e} = \log. \dfrac{P_u}{n^3D^5} - \log. \dfrac{P_e}{n^3D^5}.
\end{array}\right\} \ldots \text{Group } (G_1)$$

$$\left.\begin{array}{l}
\log. \dfrac{\Pi n^2}{V^4} = \log. \left[\dfrac{\Pi V}{n^3D^5} \times \dfrac{n^5D^5}{V^5}\right] = \log. \dfrac{P_u}{n^3D^5} - 5 \log. \dfrac{nD}{V} \\[2ex]
\log. \dfrac{Cn^2}{V^5} = \log. \left[\dfrac{2\pi nC}{n^3D^5} \times \dfrac{n^5D^5}{V^5} \times \dfrac{1}{2\pi}\right] = \log. \dfrac{P_e}{n^3D^5} \\
\qquad\qquad\qquad\qquad - 5 \log. \dfrac{V}{nD} - \log. 2\pi \\[2ex]
\log. \dfrac{P_e n^2}{V^5} = \log. \left[\dfrac{P_e}{n^3D^5} \times \dfrac{n^5D^5}{V^5}\right] = \log. \dfrac{P_e}{n^3D^5} - 5 \log. \dfrac{V}{nD} \\[2ex]
\log. \dfrac{P_u n^2}{V^5} = \log. \left[\dfrac{P_u}{n^3D^5} \times \dfrac{n^5D^5}{V^5}\right] = \log. \dfrac{P_u}{n^3D^5} - 5 \log. \dfrac{V}{nD}
\end{array}\right\} \ldots \text{Group } (G_2)$$

$$\left.\begin{array}{l}
\log. \dfrac{\Pi}{D^2V^2} = \log. \left[\dfrac{\Pi V}{n^3D^5} \times \dfrac{n^3D^3}{V^3}\right] = \log. \dfrac{P_u}{n^3D^5} - 3 \log. \dfrac{V}{nD} \\[2ex]
\log. \dfrac{C}{D^3V^2} = \log. \left[\dfrac{2\pi nC}{n^3D^5} \times \dfrac{n^2D^2}{V^2} \times \dfrac{1}{2\pi}\right] = \log. \dfrac{P_e}{n^3D^5} \\
\qquad\qquad\qquad\qquad - 2 \log. \dfrac{V}{nD} - \log. 2\rho \\[2ex]
\log. \dfrac{P_e}{D^2V^3} = \log. \left[\dfrac{P_e}{n^3D^5} \times \dfrac{n^3D^3}{V^3}\right] = \log. \dfrac{P_e}{n^3D^5} - 3 \log. \dfrac{V}{nD} \\[2ex]
\log. \dfrac{P_u}{D^2V^3} = \log. \left[\dfrac{P_u}{n^3D^5} \times \dfrac{n^3D^3}{V^3}\right] = \log. \dfrac{P_u}{n^3D^5} - 3 \log. \dfrac{V}{nD}
\end{array}\right\} \ldots \text{Group } (G_3)$$

On the axis of abscissæ $\left(\log. \dfrac{V}{nD}\right)$ let us take the point which corresponds to $\dfrac{V}{nD} = 1$. According to the mode of graduation of the scale of abscissæ, the vector having for origin this point and for extremity a point on the axis of abscissæ, is, in absolute value, equal to $1 - \log. \alpha$, $\dfrac{\alpha}{10}$ (α whole number), being the value of $\dfrac{V}{nD}$ which corresponds to a point at the extremity of the vector. The values of α inferior to 10 correspond to the points on the axis of abscissæ situated to the left of the point $\left(\dfrac{V}{nD} = 1\right)$; the values of α superior to 10 cor-

respond to the points on the axis of abscissæ situated on the right of the point $\left(\frac{V}{nD}=1\right)$. The vectors issuing from the point $\left(\frac{V}{nD}=1\right)$ measure then, with their sign, the values of $\log.\frac{V}{nD}$.

This being understood, let us draw through the point $\left(\frac{V}{nD}=1\right)$ right lines having for angular coefficients, 1, 3, 5. Let us take these lines as origins for vectors parallel to the axis of ordinates and terminating, either on the polar curve, $\log.\frac{P_e}{n^3D^5}$ or $\log.\frac{P_u}{n^3D^5}$. The vectors thus defined measure

$\log.\frac{\Pi}{n^2D^4}$, (right line for angular coefficient equal to 1);

$\log.\frac{\Pi}{D^2V^2}$, $\log.\frac{P_e}{D^2V^3}$, $\log.\frac{P_u}{D^2V^3}$, (right line for angular coefficient equal to 3);

$\log.\frac{\Pi n^2}{V^4}$, $\log.\frac{P_e n^2}{V^5}$, $\log.\frac{P_u n^2}{V^5}$, (right line for angular coefficient equal to 5).

In tracing the right line ordinate (log. 2 π) and taking this line as the origin of vectors parallel to the axis of ordinates, and terminating at one or the other of the logarithmic polars, these vectors represent

$$\log.\frac{C}{n^2D^5},\ \log.\frac{Cn^3}{V^5},\ \log.\frac{C}{D^3V^2}.$$

For these two last it is necessary, furthermore, to trace through the point $\left(\frac{V}{nD}=1,\text{ord.}=\log.2\pi\right)$ the right line for angular coefficient 5 and the right line for angular coefficient 2.

Finally the vector $\log.\rho$ is represented by the difference of the ordinates $\log.\frac{P_u}{n^3D^5}$ and $\log.\frac{P_e}{n^3D^5}$ of the two logarithmic polars corresponding to the same value of $\frac{V}{nD}$.

In practice it is important to know as a function of V, n, D, the following:

(1) The useful power, P_u (from the viewpoint of the operation of the airplane).

(2) The effective power, P_e (from the viewpoint of the motor to install on the airplane).

(3) The efficiency ρ.

Let us consider the logarithmic polar

$$\left[\log.\frac{P_e}{n^3D^5},\ \log.\frac{V}{nD}\right].$$

We have

$$\left.\begin{aligned}\log.\frac{V}{nD}&=\log.V-\frac{1}{\sqrt{10}}\times\sqrt{10}\log.n-\frac{1}{\sqrt{26}}\sqrt{26}\log.D\\ \log.\frac{P_e}{n^3D^5}&=\log.P_e-\frac{3}{\sqrt{10}}\sqrt{10}\log.n-\frac{5}{\sqrt{26}}\sqrt{26}\log.D\end{aligned}\right\}\text{..(30)}$$

Let us trace the directions ON and OD (fig. 4) making with the positive direction of the axis of abscissæ, the first the angle $(\pi+a_1)$, and the second the angle $(\pi+a_2)$, the angles a_1 and a_2 being given by the relations:

$$\text{tang. } a_1=3, \text{ tang. } a_2=5 \quad \ldots\ldots\ldots \quad (31)$$

The two equations (30) express that, for the contour OAB $\left[OA=\log.\frac{V}{nD}, AB=\log.\frac{P_e}{n^3D^5}\right]$ we may substitute the contour $OA_1B_1C_1B$, which has the same resultant. This new contour is such that:

OA_1 is parallel to the axis of $\frac{V}{nD}$ and has for magnitude log. V; A_1B_1 is parallel to OD and has for magnitude $\sqrt{26}\times\log.\ D$; B_1C_1 is parallel to ON and has for magnitude $\sqrt{10}\times\log.\ n$; C_1B is parallel to the axis of $\frac{P_e}{n^3D^5}$ and has for magnitude log. P_e.

If the proper graduations have been made on the various axes parallel to the sides of this contour (graduation in log. V on the axis of $\frac{V}{nD}$; graduation in log. P_e on the axis of $\frac{P_e}{n^3D^5}$; graduation in $\sqrt{10}$ log. n on the axis of n; graduation in $\sqrt{26}$ log. D on the axis of D), it is easy, by the construction of the contour in question, to determine any one of the vectors, knowing the magnitudes of the others. It is sufficient to remark that the contour, starting from the point O, must always end on a point of the logarithmic polar.

But this construction may be transformed in the following manner:

In present practice with airplanes, normal conditions of operation lead to the employment of propellers of a diameter of about 3 meters (9.84 feet) turning at about 800 revolutions per minute. If, for these conditions near the normal, the vectors A_1B_1 and B_1C_1 are zero, the contour $OA_1B_1C_1B$ is reduced to the contour OAB. The construction relative to normal operation is very much simplified, since it is reduced to the tracing of two lines instead of four. Now the vectors A_1B_1 and B_1C_1 are zero, if the normal values (800 revolutions per minute, 3 meters) coincide with the origin O. We are therefore led, for n and D, to a change of origin, which may be made in the following manner:

Let us consider a particular number of revolutions n_0 and a diameter D_0 for the propeller. We have then:

$$\left.\begin{aligned}\frac{V}{nD}&=\frac{V}{n_0D_0}\times\frac{n_0}{n}\times\frac{D_0}{D}\\ \frac{P_e}{n^3D^5}&=\frac{P_e}{n_0{}^3D_0{}^5}\times\left(\frac{n_0}{n}\right)^3\times\left(\frac{D_0}{D}\right)^5\end{aligned}\right\}\quad\ldots\ldots\quad(32)$$

$$\left.\begin{aligned}\log.\frac{V}{nD}&=\log.\frac{V}{n_0D_0}-\frac{1}{\sqrt{10}}\sqrt{10}\log.\frac{n}{n_0}-\frac{1}{\sqrt{26}}\sqrt{26}\log.\frac{D}{D_0}\\ \log.\frac{P_e}{n^3D^5}&=\log.\frac{P_e}{n_0{}^3D_0{}^5}-\frac{3}{\sqrt{10}}\sqrt{10}\log.\frac{n}{n_0}-\frac{5}{\sqrt{26}}\sqrt{26}\log.\frac{D}{D_0}\end{aligned}\right\}.\ (33)$$

These equations mean that for the contour OAB, and, in consequence, for the contour $OA_1B_1C_1B$, we have substituted the equivalent contour $OA_1'\ B_1'\ C_1'\ B$ (fig. 4), in which:

$$OA_1' = \log.\ \frac{V}{n_0D_0}\left(\text{directed along the axis of } \log.\ \frac{V}{nD}\right)$$

$$A_1'B_1' = \sqrt{26}\ \log.\ \frac{D}{D_0}\ (\text{directed along } OD)$$

$$B_1'C_1' = \sqrt{10}\ \log.\ \frac{n}{n_0}\ (\text{directed along } ON)$$

$$C_1'B = \log.\ \frac{P_e}{n_0^3D_0^5}\left(\text{directed along the axis of } \log.\ \frac{P_e}{n^3D^5}\right)$$

For $n = n_0$ and $D = D_0$ the vectors $A_1'B_1'$ and $B_1'C_1'$ are zero. The points $n = n_0$, $D = D_0$ are the origins of the vectors $\sqrt{10}\ \log.\ \frac{n}{n_0}$, $\sqrt{26}\ \log.\ \frac{D}{D_0}$.

The angles α_1 and α_2 defined by the relations (31) are too large and lead to ill-proportioned diagrams. We shall substitute for them the angles α_1' and α_2' such that:

$$\text{tang. } \alpha_1' = \frac{3}{2},\ \text{tang. } \alpha_2' = \frac{5}{2} \quad \ldots\ldots\ldots \quad (34)$$

The angular coefficients of the axes ON and OD are one-half less than the preceding, defined by the relations (31).

To this end it is sufficient to plot the ordinates on a scale one-half that of the abscissae. The ordinate of a point on the axis of n, instead of being equal to 3 times the abscissa of this point is only 3/2 times.

In the place of equations (33) we shall substitute the following:

$$\left.\begin{aligned} \log.\ \frac{V}{nD} &= \log.\ \frac{V}{n_0D_0} - \frac{2}{\sqrt{13}} \cdot \frac{\sqrt{13}}{2} \log.\ \frac{n}{n_0} - \frac{2}{\sqrt{29}} \cdot \frac{\sqrt{29}}{2} \log.\ \frac{D}{D_0} \\ \log.\ \frac{P_e}{n^3D^5} &= \log.\ \frac{P_e}{n_0^3D_0^5} - \frac{3}{\sqrt{13}} \cdot \frac{\sqrt{13}}{2} \log.\ \frac{n}{n_0} - \frac{3}{\sqrt{29}} \cdot \frac{\sqrt{29}}{2} \log.\ \frac{D}{D_0} \end{aligned}\right\} \quad (35)$$

Log. $\frac{V}{nD}$ and log. $\frac{V}{n_0D_0}$ are represented according to the same scale as before, OA_1' for example, in the two cases. Log. $\frac{P_e}{n^3D^5}$ and log. $\frac{P_e}{n_0^3D_0^5}$ are represented according to a scale one-half less $\left(\text{for example, } C_1''\ B' = \frac{C_1'B}{2}\right)$. As to the axes of n and of D, they have angular coefficients which are one-half of the preceding. They have

the directions designated by ON' and OD' in figure 4. The vectors which are laid out along these axes have for magnitude:

$$\frac{\sqrt{13}}{2}\log.\frac{n}{n_o} \text{ and } \frac{\sqrt{29}}{2}\log.\frac{D}{D_o}$$

The new contour is $OA_1'\ B_1''\ C_1''\ B'$; which is equivalent to the contour OAB', the point B' being a point of the logarithmic polar, of which the ordinates are laid off to a scale one-half that of the abscissæ.

In practice, we have given directly the speed V and the power P_e. It is then necessary to inscribe on the various points on the axis of $\frac{V}{nD}$ and of $\frac{P_e}{n^3D^5}$ the corresponding values of V and of P_e.

Let us take an example. Suppose that, on the axis of $\frac{V}{nD}$ $\left(\log.\frac{V}{nD}\right)$, we have marked at a given point $\frac{V}{nD}=0.7$. The vector comprised between the origin and this point represents log. (0.7). In a proposed problem, a certain velocity of translation is given, such that, in laying out, on the axis of $\frac{V}{nD}$, a suitable vector, we should find the point 0.7. If this is so, the speed V should have the value derived from the equation

$$\frac{V}{n_oD_o}=0.7$$

in which

$n_o=800$ revolutions per minute $=13.33$ revolutions per second.
$D_o=3$ meters.

From this we find

$V=0.7\times3\times13.33=28$ meters per second $=100.8$ kilometers per hour.

On the axis of $\frac{V}{nD}$, adjacent to the division 0.7 we write the number 100.8. If then at any time we have a speed of 100.8 kilometers per hour, we know that the vector log. $\frac{V}{n_oD_o}$ which must be laid off on the axis of abscissæ, will be such that its origin is at the point O, while its extremity is at the point marked 0.7 or 100.8.

Following the same principle, the axis of ordinates is graduated in horsepower. Let it be desired to find the point on this axis to which corresponds a power $P_e=100$ horsepower. In the construction of the broken line we have to trace the vector $\frac{P_e}{n_o^3D_o^5}$, in which $P_e=100\times75=7{,}500$ kilogram-meters.

$n_o=13.33$ revolutions per second; $D_o=3$

We have then

$$\frac{7{,}500}{13.33^3\times3^5}=0.013$$

Adjacent to the point already marked 0.013 on the axis of ordinates, we write the number 100.

6. STUDY OF THE PROPERTIES OF SCREW PROPELLERS—THE DIAGRAM OF THE AEROTECHNIC INSTITUTE OF SAINT-CYR.

At the Aerotechnic Institute of Saint-Cyr, for each propeller, there are first made certain observations with the propeller held at a fixed point (not propelling the car) and the following curve is then constructed:

Abscissæ N = revolutions per minute.
Ordinates Π_o = tractive pull in kilograms.
$P_e^{(o)}$ = horsepower on shaft.

Following this, with the propeller used to propel the car, similar measures are taken.

For a speed = V and revolutions per minute = N or revolutions per second = n, let the traction or thrust = Π and power on the shaft = P_e. We then compute, for the same rotative speed of the propeller, the ratios

$$\frac{\Pi}{\Pi_o},\ \frac{P_e}{P_e^{(o)}},\ \rho=\frac{\Pi V}{75 P_e}$$

It is assumed, as a sufficient first approximation in practice, that these ratios are simple functions of $\frac{V}{nD}$. Curves are next plotted, for which the values of $\frac{V}{nD}$ are abscissæ and the values of the preceding ordinates.

Let us consider, for a given type of propeller, the ratios:

$$\alpha_o=\frac{\Pi_o}{n^2 D^4}.\ \beta_o=\frac{P_e^{(o)}}{n^3 D^5}$$

According to Col. Charles Renard, who was the first to propose the use of these expressions in the study of the screw propeller at a fixed point, these ratios, for each type of propeller, are constant; they are the same for all similar propellers deduced from the type. If this is so, the ratios $\frac{\Pi}{\Pi_o}$, $\frac{P_e}{P_e^{(o)}}$ are proportional to the magnitudes $\frac{\Pi}{n^2 D^4}$, $\frac{P_e}{n^3 D^5}$, considered by M. Eiffel.

But if the coefficients α_o, β_o of Col. Renard, $\frac{\Pi}{n^2 D^4}$, $\frac{P_e}{n^3 D^5}$ of M. Eiffel, vary with n, it may be assumed that this variation will remain nearly the same at all speeds of translation. The curve which represents $\frac{\Pi}{\Pi_o}$ as a function of $\frac{V}{nD}$ may be the same, whatever the value of n, so long as the curve representing $\frac{\Pi}{n^2 D^4}$ as a function of $\frac{V}{nD}$ varies with n. This is the reason for the mode of representation adopted at the Aerotechnic Institute of Saint-Cyr.

CHAPTER IV.

THE RESULTS OF EXPERIMENT.

1. WITHIN WHAT LIMITS MAY THE RESULTS OF EXPERIMENTS MADE ON MODELS BE APPLIED TO FULL-SIZED MACHINES?

We have seen, Chapter II, that experimenters have studied the problem of the resistance of the air either on reduced size models, or on models nearly full size or on actual full-size models. The most complete and important results are those obtained by M. Eiffel on models.

One question presents itself immediately: Are all these experimental results comparable among themselves? To what extent, for actual airplanes, may we use the results of experiments carried out on a reduced scale?

Consider a body surrounded by the air and having a velocity of translation V relative to it. If S is a suitably chosen surface, distinctive or characteristic of the form or design, the resistance of the air may be expressed by the equation:

$$R = KSV^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

K being a coefficient of the nature of a density.

We may first note a law sufficiently exact in a great number of cases, and which was formulated in the seventeenth century by Huyghens, Mariotte, and Pardies as follows:

If the density of the air remains the same (experiments carried out in air at sensibly the same temperature and pressure), the coefficient K depends solely on the form of the body studied.

For similar bodies, the coefficient K is constant, whatever may be the value of the velocity V. The realization of an experiment on a reduced scale similar to an experiment full size is easy. We may choose at will the scale of the model and the velocity for the experiment.

We have assumed that the body is given a movement of translation relative to the air; such a restriction is not essential. The movement of the body in the air may be more complex, accompanied, for example, by rotation; such is the case of a screw propeller. In any such case, however, the peripheral velocities for the model and for the full-sized machine should be in the same ratio as the velocities of translation or advance.

For sustaining propellers, the speeds of advance are zero, and this condition is fulfilled. If D is the diameter of the propeller and n the number of revolutions in unit time, if S is the area of the circle swept by the blades, we draw readily from (1) the laws announced in 1903 by Col. Charles Renard; viz, for similar propellers we have:

$$\frac{\Pi_o}{n^2D^4} = \text{constant}, \quad \frac{P_u^{(o)}}{n^3D^5} = \text{constant}$$

where Π = traction or thrust of propeller and P_u = useful power expended.

It follows immediately, from what has been said above, that these formulæ may be extended, with different coefficients, to *propulsive* propellers when the combination of speed of advance and of rotation gives, for homologous points, speeds equally inclined to the axis. In other words, provided the values of $\frac{V}{nD}$ are the same for two propellers geometrically similar, the results of experiments made on one of them are applicable to the other. We may apply to traction, screw propellers geometrically similar to equation (1) by considering that the coefficient K is a function of $\frac{V}{nD}$.

For the wings of an airplane and for airplanes complete, M. Eiffel assumes that K is a simple function of the form of the body under investigation. It is on this assumption that the formulæ of paragraph 1 of Chapter III have been established.

M. Eiffel bases his conclusions in this regard on a comparison of results of tests made, on the one hand, by Commandant Dorand on a biplane in free flight, and, on the other hand, by himself by means of a fan on a model of this airplane built to a scale of 1/14.5.

Let us denote by $R_x V^2$ the drift (equal to the thrust of the propeller) measured on the airplane full size. Let us call μ_x the coefficient by which it is necessary to multiply the results of the experiments on the full-sized machine in order to pass to the model. The drift of the model at a scale of 1/14.5 will be, at the velocity V, equal to

$$\frac{1}{\mu_x} \times \frac{R_x V^2}{(14.5)^2}$$

This drift, brought to a speed of 10 meters (32.8 feet) per second, has for value,

$$r_x' = \frac{1}{\mu_x} \times \frac{R_x V^2}{(14.5)^2} \times \left(\frac{10}{V}\right)^2 \quad \ldots \ldots \ldots \ldots \quad (2)$$

Similarly, the thrust on the model, calculated from the thrust $R_y V^2$ measured on the airplane and brought to the speed of 10 meters per second, has for value,

$$r_y' = \frac{1}{\mu_y} \times \frac{R_y V^2}{(14.5)^2} \times \left(\frac{10}{V}\right)^2 \quad \ldots \ldots \ldots \ldots \quad (3)$$

These values r_x' and r_y' may be compared with the values r_x and r_y measured directly on the model placed before the fan.

From this the following values were found:

$$\mu_x = 0.99 \qquad r_x' = \frac{1}{0.99} r_x$$

$$\mu_y = 1.01 \qquad r_y' = \frac{1}{1.01} r_y$$

M. Eiffel believed that he was justified in concluding from these results that the law as stated above (law of similitude, supposing K constant) was verified within 1 per cent. We do not consider the conclusion justified. The measurements of M. Eiffel and those of

Commandant Dorand were not made under the same conditions. In those of M. Eiffel the model of the propeller was fixed; in those of Commandant Dorand the propeller revolved before sustaining planes. Now the wind from the propeller has on the wings a certain action; it therefore seems to result that the agreement within 1 per cent between the results of M. Eiffel and those of Commandant Dorand shows that if the experiments had been carried out under conditions really comparable, the results obtained would have shown a definite divergence.

Comparative experiments on surfaces and their models (ratio of 1/10) have, furthermore, been made at the same relative velocity at the laboratory of Saint-Cyr (method by car) and at the Eiffel laboratory. For varying values of the angle of incidence i, the values of K_x and K_y were plotted for a certain number of surfaces. The following results were obtained:

(*a*) The curves for K_y have the same general form; those determined by the car are, in general, above those determined from the model; they are, moreover, readily distinguished from them.

(*b*) The curves for K_x likewise have the same general form; those determined by the car are sometimes above and sometimes below the others. On the whole, it is very difficult to draw any conclusions from these divergencies. On the one hand the forces to be measured are very small; on the other, with the surfaces parallel to the current of air, the nature of the surfaces (duck for the airplane at Saint-Cyr and well polished wood for the model), with their roughness or slight deformations, may assume the highest importance.

(*c*) As regards the centers of thrust (intersection of the resultant of the air resistance with the chord of the profile of the surface in the plane of symmetry), the agreement is in general satisfactory. However, for certain surfaces, M. Eiffel finds this point a little farther from the attacking edge than the Institute of Saint-Cyr; for other surfaces, it is the inverse.

According to this result, it does not seem that M. Soreau is correct in assuming that the law of similitude is less exact in regard to the location of the resultant of the resistance than in regard to its magnitude. However, we shall find later certain other experimental results which seem to justify this conclusion.

(*d*) As to the distribution of the pressure (both above and below normal) over the two faces of the surfaces, the general agreement is quite satisfactory. The systematic divergence is marked by this fact that the values of the drop of the pressures below normal (negative pressure or suction) on the upper face are greater for the car than for the fan, which agrees with the comparison of the values of K_y. For certain angles, near the attacking edge, the experiments with the car indicated a relatively greater value of the drop below normal pressure.

In the comparison of the results obtained with the surfaces tested full size on the car and with models 1/10 tested by the fan (same relative velocity), there was found the same general form of curve for the results, with the vertical force appearing systematically a little greater for the car than for the fan.

M. de Guiche deduces from his experiments on curved aerofoils the following conclusions:

Two aerofoils of the same spread, but with different profiles geometrically similar, are not comparable.

He has studied the two following forms:

(*a*) Thick aerofoil (maximum thickness, 101 millimeters (4 inches)) with circular curvature.
Chord=120 centimeters (47.3 inches).
Maximum height of mean line segment÷length of chord=1/10 (mean line segment=intersection of plane of symmetry with the surface equidistant between the two faces, upper and lower).
Maximum height of upper line segment÷length of chord=1/7 (upper line segment=intersection of plane of symmetry with the upper face of aerofoil).
Spread=170 centimeters (68 inches).
Radius of curvature of the upper face=130 centimeters (51 inches).
Radius of curvature of the lower face=252 centimeters (99.3 inches).
The two surfaces are joined by half circles of 14 millimeters (56 inches) radius.
(*b*) Aerofoil of which the section is a proportional reduction of the preceding, in the ratio of one-half.
Maximum thickness=50 millimeters (2 inches).
Spread=170 centimeters (68 inches).
Chord=60 centimeters (23.7 inches).
Radius of curvature of upper face=65 centimeters (25.5 inches).
Radius of curvature of lower face=126 centimeters (49.7 inches).
Radius of connecting circles=7 millimeters (0.28 inch).

These similar profiles are subject to reductions below the normal pressure very different at corresponding points. For the same angle of incidence there is no relation between the distribution of pressures above and below normal on the two faces. The variations of the thrust and the center of the thrust are very different in the two cases. On form (*a*) the point of application of the resultant advances constantly toward the attacking edge as the angle of incidence increases up to 25° (limit of the experiment). On form (*b*), on the contrary, the point of application of the resultant advances toward the attacking edge until the angle i=about 12°, then for values of i greater than 12° it returns toward the center of the wing.

The curve of the values of K_x is sensibly the same for the two forms, but the curve of the values of K_y takes very different forms in the two cases. For form (*a*) the values of K_y increase constantly up to $i=25°$. For form (*b*) K_y passes through a maximum for $i=12°$. This appears to be the critical angle for this form; it marks at the same time the maximum of K_y and the most advanced position of the force.

We have insisted on these results of experiment which show clearly that, for wings and for airplanes, the law of similitude based on an assumed constant value of K is not exact.

Nevertheless, we believe that this law is sufficient for the guidance of constructors regarding the aerodynamic qualities of aerofoils, or of complete airplanes for which the design is in hand.

Regarding screw propellers, this law is not of itself sufficient. It is not enough that the experiments on a propeller full size and on its model should be made in such manner that $\frac{V}{nD}$ shall have the same value. It is necessary, further, that the speed of advance V and, in consequence, the peripheral speed πnD shall be the same. Equation (1) is applicable for propellers moving forward through the air on condition of considering K as a function not only of $\frac{V}{nD}$ but of V.

It is thus necessary, in order to keep the revolutions of the propeller within an upper limit of 3,600, to hold to a scale not exceeding one-third for the models of screw propellers.

Theoretical considerations developed by M. Jouguet, and which would require too much space for extended notice here, show that this departure from the law of Huyghens, Mariotte, and Pardies is due to the compressibility of the air, which becomes of importance at the high relative velocities of the blades and the air which are realized in the case of screw propellers.

These same theoretical considerations show that, for the speeds of advance used in aviation (25 to 30 meters (82 to 98. 4 feet) per second), a more exact law of similitude may be realized by corrections for the perturbation due to the viscosity of the air. To this end it would serve to test the model at a speed equal to that of the airplane multiplied by the linear ratio between airplane and model.

If V is the speed of advance of the airplane and v that of the model at the scale ratio of $\frac{1}{\lambda}$, we have for the resistances of the air

$$\frac{R_V}{r_v}=\frac{K_V}{K_v}\lambda^2\left(\frac{V}{v}\right)^2$$

If then we take $$\frac{V}{v}=\frac{1}{\lambda} \text{ and } K_V=K_v$$

we shall have $R_V=r_v$.

2. THE DISPLACEMENT OF A BODY UNDER TEST THROUGH THE AIR AND THE MOVEMENT OF THE AIR WITH RESPECT TO A FIXED BODY.

M. de Guiche has found for certain surfaces, notably for planes' distributions of pressure differing from those found by M. Eiffel. The latter has found, on the following face, only zones of pressure below the normal. M. de Guiche, on the contrary, for angles of incidence less than 20°, has found zones of pressure above the normal. Now the experiments in the two cases are very numerous and have been made with the greatest care. The differing results are, then, due to phenomena which appear in one of the modes of experimentation and not in the other.

The principle of relative motion is, in fact, not in question. What is in doubt is, whether, by the method of the tunnel, conditions can be developed which permit the assumption of equal relative motions in the two cases.

Let us consider a solid which moves with a velocity V in an indefinite medium originally at rest. At a given moment, far from the origin of movement, we may distinguish two regions in the space surrounding the body under investigation. One, formed of regions far removed from the solid, is not disturbed by the passage of the latter. At each of these points there is a velocity relative to the moving body of $-V$, equal, parallel and in the opposite direction to the velocity of translation V. The other region, situated near the body, is disturbed by the movement of the latter. Relative to the moving body, each point in this region has a velocity which is the resultant of

(*a*) A velocity $-V$ equal, parallel, and opposite in direction to the velocity of the body.

(*b*) A velocity W due to the motion of the solid body.

This last velocity is a function of the disturbance brought into the medium by the passage of the body. It depends, furthermore, not

only on the form of the body, on its dimensions, on the degree of polish of its surface, but also on the properties of the medium, its viscosity, and the initial conditions of the movement.

Let us now assume the solid fixed and the surrounding medium to be displaced relative to it. This mode of experimentation should realize the conditions which require the application of the principle of relative movement. For this it is necessary that, from the moment when permanent conditions are established, the velocity at each point in the medium disturbed by the presence of the solid should be equivalent to the resultant of the two velocities $-V$ and W.

It is assumed in the method of the tunnel that such a resultant is obtained by giving to the fluid, in the undisturbed parts, a velocity $-V$. In particular, in the experiments in the midst of a moving column of air, it is assumed that it suffices to draw the air into one of the extremities of the tunnel sufficiently removed from the body placed in the interior. Now this fact does not imply that the velocity, in the disturbed part, is equivalent to the resultant of the two velocities $-V$ and W.

The viscosity of the fluid may intervene in such manner as to cause the state of the disturbed region to depend on the mode of producing the relative motion. Experiment alone can decide.

Now, as we shall see at a later point, comparison of the experiments of M. de Guiche and of M. Eiffel shows that the phenomena observed in the method with the tunnel are not always identical with those which result from the movement of a solid body in free air.

We should note, however, that the study of pressures below normal made at the Institute of Saint-Cyr (method by use of car) do not show, in comparison with the experiments of M. Eiffel, the differences which M. de Guiche has noted. The question involved here does not seem to be completely elucidated. In particular it seems desirable that M. de Guiche should reproduce certain of his experiments with his apparatus at Saint-Cyr in order to establish the atmospheric pressure in the free branches of the manometers used for measuring the pressures above and below the normal.

In any case, the solution of such a question can be of interest only from the viewpoint of the science of aerodynamics. It does not present the same interest from the viewpoint of practical aviation. From the latter viewpoint, we consider as equivalent the two methods of producing the relative movement between the air and the body under investigation.

3. THE AERODYNAMICS OF THE PLANE—PLANES ORTHOGONAL.

When the body is a thin orthogonal plane we may, in practice, take for the coefficient K of equation (1) the value $K_{90}=0.080$ (0.0015 pound second-feet). M. Eiffel has found that this coefficient varies

(a) With the extent of the surface;

(b) For a surface of given extent, with the form of the contour.

M. Soreau has proposed, in order to represent the various values found by M. Eiffel, the empirical formula:

$$K_{90}=\frac{0.0888\,S^{0.06}}{1+0.116\,S^{0.06}}$$

The surfaces on which M. Eiffel has operated are, in general, too small; the perturbations caused by the influence of the bound-

aries are preponderant. It would be necessary to operate on surfaces of which one of the sides has a length greater than 1 meter (3.28 feet). With such surfaces, steady conditions, characterized by isobars, parallel to the sides of the plate, would be established and would assume the preponderance. We might thus determine for K_{90} a value characteristic of this regular regimen, and which would be independent of the area of the plate and of the form of its contour.

Experiments over so wide a field have not been made. However, M. de Guiche, studying a rectangular plate 100 by 60 centimeters (39.4 by 23.6 inches), found $K_{90}=0.083$.

In order that the thickness of the plate normal to the direction of relative motion may have any influence, it is necessary that this thickness be of the order of the transverse dimensions of the plate. From the point where the thickness of the plate is equal to one of the transverse dimensions, the coefficient K_{90} varies, first decreasing and then increasing as the thickness increases.

M. Eiffel has studied, by means of the fan, the combination formed by two thin orthogonal planes separated by a variable distance. He has been led to the following conclusions, applicable, for example, to disks 30 centimeters (11.8 inches) diameter:

(1) The force on the combination diminishes, first, in proportion as the separation increases. It passes through a minimum for a certain value of the separation, and then increases again.

(2) The force on the combination does not begin to exceed the force on an isolated plate until the plates are very considerably separated.

(3) The force on the combination has always been less than the sum of the forces on each of the plates taken alone. The effect of shielding due to the forward plate makes itself felt, even when the plates are very far apart.

(4) The pressure on the plate exposed directly to the wind is approximately independent of the separation, but it always moderately exceeds the pressure on an isolated plate.

(5) The shielded plate is first drawn toward the forward plate. This attraction varies, first increasing in absolute value with the separation of the plates, passing through a maximum corresponding to the minimum of the total force, and then decreases to zero. This attraction is then changed into repulsion, of which the absolute value increases with increase in the separation of the plates.

(6) On the plate directly exposed to the wind, the mean pressures on the leading face (above normal) and on the following face (below normal) are sensibly independent of the separation of the plates.

(7) The mean pressures on the leading and following faces of the shielded plate are below normal, so long as the plates are not very far apart.

The mean drop in pressure on the leading face is, in absolute value, at first greater than that on the following face.

The total mean force on the plate is such as to tend to bring together the two plates (attraction for the shielded plate).

For a suitable separation of the two plates, not only the mean forces but also the forces at each point on the shielded plate are sensibly zero, and the resultant mean force is zero.

Finally, when the separation of the plates increases beyond a certain limit, the mean total pressure on the shielded plate becomes such as to tend to produce further separation (repulsion of the shielded plate).

4. AERODYNAMICS OF THE PLANE—PLANE INCLINED TO THE DIRECTION OF RELATIVE MOVEMENT—PLANE ISOLATED.

(a) DISTRIBUTION OF PRESSURES, ABOVE AND BELOW NORMAL.

(1) As soon as the plane exceeds certain dimensions there is found, on both the leading and following faces, a central zone where a regular regimen becomes established. The existence of this zone is shown by isobars parallel to the attacking edge. In this entire zone the phenomenon is defined by the distribution of the pressures along the line of steepest gradient. The study of this serves, in many cases, to characterize a surface.

M. Eiffel has studied only this mode of distribution of pressures above and below normal. The dimensions of the sides of the planes which are normal to the wind were, in some cases, too small and the experimenter was able to observe only the pressures in the disturbed zone near the boundaries of the plane.

(2) The boundary zones of disturbance have a width sensibly constant, which is, for the leading edge, some 20 centimeters (7.9 inches), and for the following edge, from 40 to 50 centimeters (15.8 to 19.7 inches). In consequence, in order that the regular regimen may be in evidence the plane should have a spread at least twice the width of the zones of disturbance.

(3) **Special study of the leading face of plane:**

Angles of incidence less than 20°.

Bourlet has proposed the following formula deduced from theoretical considerations:

Total pressure on leading face:

$$P = \frac{4}{3}\frac{C}{100}(\sin i)^{0.4} S l^{-\frac{1}{4}} V^2$$

System of units, kilogram-meter-second.

S = area.

l = depth in direction of wind.

V = speed.

C = coefficient which depends on the form of the plane.

C is of the form.

$$C = A - B\frac{L}{S}$$

where L = perimeter of plane.

M. de Guiche has found by experiment:

$$A = 3.8 \qquad B = 0.11$$

With these values the formula becomes:

$$P = \left(0.050 - 0.0014\,\frac{L}{S}\right)(\sin i)^{0.4} S l^{-\frac{1}{4}} V^2$$

For surfaces sufficiently large

$$P = 0.050\,(\sin i)^{0.4} S l^{-\frac{1}{4}} V^2$$

This formula is not applicable for angles of incidence, i, such that the pressures measured along a line of greatest slope become less than normal. The pressures, thus measured, decrease in fact continuously from the forward edge. They may even become negative in the vicinity of the following edge. The existence of pressures below the normal comes into evidence for smaller angles of incidence as the ratio of the fore and aft to the transverse dimensions is smaller. In the experiments of M. de Guiche it was determined that such pressure below normal began to appear as follows:

For surface 180 by 120 centimeters (70.87 by 47.24 inches) from $i=20°$.
For surface 180 by 80 centimeters (70.87 by 31.50 inches) from $i=10°$.
For surface 180 by 40 centimeters (70.87 by 15.75 inches) from $i=8°$.

The lateral turbulent zones show pressures less than those found at an equal distance from the attacking edge.

(4) Special study of leading face of plane:

Angles of incidence exceeding 20°.

The formula of Bourlet is not applicable. The maximum pressure is no longer at the leading edge. This becomes, when the angle increases, a zone of lesser pressure like the three other sides.

(5) Special study of following face of plane:

Angles of incidence less than 20°.

In the regular zone (isobars parallel to the attacking edge), for depths of plane sufficient to render negligible the influence of the boundaries, the pressure at a given point and for a given angle of incidence appears to be a function solely of its distance from the attacking edge.

M. Eiffel has not observed counter pressures on this back face of the plane. On the other hand, M. de Guiche has very clearly observed them. This is one of the differences between the results obtained by one or the other of the methods of experimentation.

(6) Special study of following face of plane:

Angles of incidence exceeding 20°.

There are no longer any counter pressures on the following face. The distribution of the pressures below normal becomes quite uniform.

(b) TOTAL FORCE.

(1) According to M. Eiffel, the total force passes through a maximum for an angle of incidence of about 37°.

According to M. de Guiche the total force increases up to angles of 45°; beyond that it remains sensibly constant.

For angles of inclination comprised between 0 and 10°, rectangular plates for which the transverse dimensions are greater than the fore and aft are subject to the greatest total pressures.

For angles less than 10°, the following formula may be taken:

$$\frac{Ki}{K_{90}}=\left(3.2+\frac{n}{2}\right)\frac{i}{100} \text{ (i in degrees)}$$

(2) The center of pressure, that is to say, the point where the line of the resultant force intersects the thin plane, is at the center of the plate when the plane is perpendicular to the line of relative move-

ment. In proportion as the inclination decreases, the center of pressure advances toward the leading edge, even to the smallest values of the angle.

(3) The resultant of the air pressures is, for inclinations exceeding about 10°, sensibly perpendicular to the plane. For smaller angles of inclination the angle of the resultant with the perpendicular to the line of relative motion is greater than the inclination of the plane; the resultant is inclined to the normal to the plane behind this normal.

(4) Thick plates.

If the thickness of a plane plate is increased, leaving the ends plane and at right angles with the two faces, there is introduced but slight change as compared with the phenomena described for thin planes, except that the head resistance is increased as the thickness is made greater.

(5) Thick plane plate with leading or following edge provided with cutwater.

With a cutwater on the following edge, the ratio drift/lift is notably less than without. It is more advantageous to find the following than the leading edge.

It is preferable to have the forward cutwater edge toward the lower rather than the upper side.

Finally, the law of variation of the center of force is entirely different from that indicated above for planes.

5. AERODYNAMICS OF THE PLANE—PLANES IN TANDEM.

M. de Guiche has experimented with three elements of aluminum of 1 meter (39.4 inches) spread, 20 centimeters (7.9 inches) fore and aft width, and 8 millimeters (0.32 inches) thickness. He has studied the distribution of the pressures along the median line of maximum gradient, forward and aft, in the three following cases:

(*a*) Elements in contact (interval zero).
(*b*) Elements separated by interval of 5 centimeters (1.97 inches).
(*c*) Elements separated by interval of 10 centimeters (3.94 inches).

(1) Study of forward face:

The character of the variation of the diminution of the pressures from the leading to the following edge is the same for the separated elements as for those in contact. The pressure diminishes continously from the leading to the following edge.

Second element: If we consider the second or middle element, the maximum pressure in the vicinity of the leading edge does not become sensibly equal to that for the leading edge of the first element unless the separation of the two elements is equal to 10 centimeters (3.94 inches). For the distance of 5 centimeters (1.97 inches) the maximum pressure on the second element is inferior to the maximum pressure on the first element. As regards the forward face, then, the second element does not behave as if it were alone unless the distance of the two elements is equal to 10 centimeters (3.94 inches).

Third element: The maximum pressure near the leading edge is always clearly less than that for the second element.

Total pressure on forward face: For angles of incidence less than 15°, it is less for the separated elements than when they form a continuous surface.

For angles between 15° and 25°, it is greater for the separated than for the continuous elements.

For angles greater than 25°, it is sensibly the same for the separated as for the continuous elements.

(2) **Study of rear face:**

The first element shows pressures below normal, similar to those for the isolated plane (no pressures above normal).

On the second element, similarly, only pressures below normal are observed. For small angles of incidence (4° to 6°) the drop below normal pressure near the forward edge is much more pronounced than for the first element.

This relation is less marked in proportion as the angle of incidence is increased; it is even reversed for angles exceeding 30°.

On the third element, positive pressures are observed for very small angles of incidence and then pressures below normal for greater angles.

As to the total drop in pressure on the rear face, it is in general less for the separated than for the continuous elements.

(3) **Total force.**

This is, in general, less for the separated than for the continuous elements.

The center of pressure of the combination, defined by its distance from the forward edge of the first element, changes less (with variable angle of incidence) for the elements with separation than when continuous.

6. AERODYNAMICS OF PLANE AEROFOILS, ARRANGED STEPWISE.

M. de Guiche has studied the disposition of planes stepwise.

The planes are parallel; the leading edge of each element is on the normal passing through the following edge of the preceding element.

The steps are arranged in two ways: Direct, if in going in the direction of the wind one descends the steps; reverse, if in going in the direction of the wind one mounts the steps.

The planes of brass, which M. de Guiche has used, have a spread of 100 centimeters (39.4 inches), a depth of 12 centimeters (4.7 inches), a thickness of 4.5 millimeters (0.18 inches); the separation of the planes was either 2 centimeters (0.79 inches) or 4 centimeters (1.58 inches). The number of planes was three.

(1) **Planes direct: Forward or lower face.**

First element: Diminution of pressure from the leading to the following edge.

Second element: Inversely as compared with the case of planes in tandem, the leading edge is subject to a notable negative pressure and the maximum positive pressure is produced to the rear of the leading edge.

Third element: The maximum positive pressure is produced at a point lying behind the leading edge, but, in general, the leading edge is not subject to a negative pressure.

These phenomena (relative to the second and third elements) become more pronounced for the separation of 4 centimeters than for that of 2 centimeters.

(2) Planes direct: Following or upper face.

First element: This is subject to a negative pressure. It behaves nearly as though it were alone.

Second and third elements: The negative pressures are less marked than for the first element. There are even positive pressures produced near the following edge.

(3) Planes reverse: Forward or lower face.

This system has been studied at angles of incidence of 6°, 8°, and 15°, and for a separation of the elements equal to 4 centimeters (1.58 inches).

First element: If for an incidence of 6° we consider the displacement cylinder of the first element, it is seen that the second and the third elements project into this cylinder. There results, for this element, a diminution of pressure on the leading edge. The latter is no longer subject to the maximum pressure, which is carried aft. This phenomenon disappears at incidences of 8° and 15°. The decrese in the pressure then follows continuously from the leading edge aft.

Second and third elements: For angles of incidence of 6° and 8°, the phenomena are the same as for the steps in direct form.

At 15°, the second element is almost shut out by the first; this element is subject entirely to a negative pressure. The third element is subject in part to positive pressure; there is, however, negative pressure near the leading edge.

(4) Planes reverse: Rear or upper face.

At the incidence of 8°, the negative pressure on the second and third elements is marked near the leading edge; it is from 1.5 to 2.5 times as great as on the first element.

There is here a phenomenon similar to that which has been observed with Venturi tubes disposed in series.

(5) Total force.

The total force on the system is less than for a continuous plane of the same surface.

The drift is more considerable on account of the more numerous edges.

This type of combination is not to be recommended.

M. Eiffel has determined the total force and the drift for planes parallel to each other and without stepwise interval. We shall return later to the consideration of curved aerofoils, for which the results are similar.

7. AERODYNAMICS OF CURVED AEROFOILS—ISOLATED.

There has been made in France a very considerable number of experiments on curved aerofoils, isolated.

M. Eiffel has operated on models; a very considerable number of them have a spread of 90 centimeters (35.5 inches) and a depth along the chord of 15 centimeters (5.9 inches) (aspect ratio = 6). He has not used aerofoils of less than 45 centimeters (17.8 inches) spread with the same depth as above. M. Eiffel considers the mean surface; that is, the surface equidistant from the two actual surfaces of the

aerofoil. The nominal height of the curved contour is the ratio of the height of the arc for this mean surface to the chord.

M. de Guiche has studied aerofoils for which the spread is 170 centimeters (67 inches) and the depth along the chord 120 centimeters (47.3 inches) (aspect ratio = 1.4). However, in certain cases the depth was reduced to 60 centimeters (23.6 inches).

At the Institute of Saint-Cyr there have been studied aerofoils for which the spread varies from 5 to 10 meters (16.4 to 32.8 feet), the depth varying from 2 to 2.5 meters (6.56 to 8.40 feet).

(a) DETERMINATION OF THE PRESSURES POSITIVE AND NEGATIVE.

(1) Beyond a certain value of the spread there develops a regular regimen, involving the entire surface with the exception of two lateral turbulent bands. This regimen is indicated by isobars parallel to the leading edge.

It appears that the fairly uniform width of the bands of turbulence does not exceed 20 centimeters (7.9 inches). It is desirable, therefore, to use no aerofoils with a spread less than 40 centimeters (15.8 inches).

(2) Each one of the faces of the aerofoils joins in the support, but not equally. The pressures supported by the lower face, at ordinary incidences of flight, assume a smaller share of the total force than the negative pressures on the back.

(3) The lower face is subject to the influence of the upper face, but is itself without influence on the latter.

(4) The curvature of the back determines the distribution of the negative pressures; it deviates upward the lines of air flow.

An exaggerated height of the arc for the curvature on the back produces a harmful counter pressure on the following edge of the wing.

The displacement of the maximum height of arc toward the leading edge carries a corresponding displacement of the maximum value of the negative pressure, and in consequence a reduction in the drift value.

The ideal would be to suppress in an aerofoil harmful pressures, positive or negative (that is to say, to have on the upper face only negative pressures and on the lower face only positive pressures), and to find the pressure of the atmosphere only at the following edge, where the lines of air flow join together without shock. The key of the problem seems to involve the maximum height of the arc and position between the leading and following edges.

(5) The negative pressures are not modified by the form of the leading edge; this has only a local influence. It has been said that this edge should be rounded, under a penalty of a reduction of the negative pressures on the back of the aerofoil. There is nothing to this. It is better to make it sharp in order to facilitate its penetration.

A French engineer, M. Constantin, has proposed a concave form for the leading edge. M. de Guiche found that this form did not show the advantages which its inventor had anticipated. However, it is only fair to say that by means of the fan, M. Eiffel arrived at an opposite conclusion.

(6) In general for angles involved in aviation, the modes of variation of pressures, positive and negative, are similar in all the results obtained by different experimenters.

The modes of variation of the negative pressures on the back fall into two principal types.

(*a*) The negative pressure starts from a certain value, often small, near the leading edge; it then increases continuously passing aft, passes through a maximum, then decreases regularly to the following edge.

This mode of distribution is found with thick aerofoils (monoplane type) of 80 to 100 millimeters (3.15 to 3.79 inches) maximum thickness.

(*b*) The negative pressure is very pronounced at the leading edge. Passing aft, the value decreases, passes through a minimum, then increases, passes through a second maximum, in general less than the first, and finally decreases regularly to the neighborhood of the following edge.

M. Eiffel has found such modes of variation with thin planes (biplane type) of 20 to 35 millimeters (0.79 to 1.38 inches) thickness.

The combination of the two modes (*a*) and (*b*) is found very marked in the case of aerofoils presenting steps on the back. The lower face has a regular curvature, but the upper face is formed stepwise. The combination thus constituted gives the impression of being formed of two or three aerofoils joined one behind another.

With one projecting ridge (up to incidences of 5°) there is found, in going from the leading to the following edges, a maximum of negative pressure, a minimum, and finally a maximum.

With two projecting ridges (up to incidences of 5°) there is found a maximum of negative pressure, a minimum, a maximum, a minimum, and finally a maximum.

For an incidence of 10°, the distribution is the same as for mode (*b*), but with several maxima and minima in the depth of the surface (one projecting ridge, two minima and a maximum; two projecting ridges, two minima and two maxima).

(7) We have now examined the mode of distribution of the negative pressures on the back of the aerofoil. If next we consider the lower face, there are found, in general, no negative pressures except near the following edge. On the remainder of the face the pressures are positive. In general, in passing from the leading edge aft, the pressure increases first a little, passes a maximum, and then decreases to the following edge.

However, certain aerofoils (with projecting ridges on the back) show, for angles of incidence near 0°, negative pressures near the leading edge.

(8) Two aerofoils of the same spread and with similar but not equal sections are not comparable.

(9) However, as pointed out by M. de Guiche, it is the aerofoil with the largest value of the aspect ratio which presents the most marked advantages. It is desirable that extended investigations should be made on aerofoils of different depths with the same spread—that is to say, on aerofoils with varying values of the aspect ratio and geometrically similar in section—in order to determine if for a given section, there is a best value of this ratio, and what is this value.

It may be noted that M. Eiffel considers 6 as this best value of the aspect ratio.

(6) Total resultant and point of application.

(1) The total resultant force continuously increases with the angle of incidence, at least within the range of interest in aviation.

As to the force center (intersection of the total resultant with the chord of the section) it approaches nearer and nearer to the leading edge as the angle of incidence increases from zero, at least within the range involved in aviation. This is the inverse of what takes place with a plane.

If we pass beyond the angles involved in aviation (angles less than 10°), the force center again recedes from the leading edge as the incidence increases.

(2) If aerofoils of varying thickness have the same surface of mean curvature, they are the more advantageous as the thickness is less.

M. Eiffel has shown, in effect, that under these conditions the ratio $\frac{K_x}{K_y}$ continuously increases with the thickness of the aerofoil.

It follows that if it is desired to compare the qualities of two aerofoils, it is necessary to use only forms with the same maximum thickness and with the same aspect ratio.

(3) A distinction may be drawn between thick and thin sections for aerofoils.

Thick aerofoils are suited more especially to monoplanes, because they must contain solid structural members. Such aerofoils, in general, have a thickness of about 90 millimeters (3.55 inches) at one-third and 50 millimeters (1.97 inches) at two-thirds of the depth from the leading edge.

Thin aerofoils are used for biplanes. Their maximum thickness varies between 30 and 90 millimeters (1.18 and 3.55 inches).

For good, thick aerofoils and for an angle of incidence $i=5.6°$ we have $\frac{K_x}{K_y}=0.079$, with $K_x=0.0043$ and $K_y=0.055$.

These are values suited to a monoplane.

With $i=2.1°$ we have $\frac{K_x}{K_y}=0.069$, with $K_x=0.0019$ and $K_y=0.027$.

But this angle is too small for a normal angle of incidence for a plane.

For a thin aerofoil of thickness equal to 63 millimeters (2.48 inches) and an angle of incidence $i=5.3°$ we have $\frac{K_x}{K_y}=0.058$, with $K_x=0.0023$ and $K_y=0.040$.

For a thin aerofoil of thickness equal to 45 millimeters (1.77 inches) and an angle of incidence $i=8°$ we have $\frac{K_x}{K_y}=0.091$, with $K_x=0.0055$ and $K_y=0.060$.

These values are suited to the wings of biplanes.

(4) The lateral edges of the wings exert a feeble influence on their quality. However, the trapezoidal form with the larger base behind seems more effective than the rectangular form.

(5) With certain forms of wing (wing provided along the leading edge with a concave edge forming a sort of crest, wing with thick,

rounded leading edge), M. Eiffel has found discontinuities in the curves of K_x and K_y in relation with different regimens of the flow of the air. But such phenomena are exceptional.

8. AERODYNAMICS OF CURVED AEROFOILS—COMBINATIONS OF CURVED AEROFOILS—ARRANGEMENT IN BIPLANE.

M. Eiffel has determined the varying values of R_x, R_y, F_x, F_y, for the various parts of a Dorand biplane, these parts being subject to experimental investigation assembled in complete form, or separate.

This biplane consists of a principal cell formed of two identical planes 14.5 by 2.25 meters (47.56 by 7.38 feet). These planes are separated in height by a distance of 1.95 meters (6.4 feet), that is, by a height sensibly equal to the depth of the plane. They are stepped a distance of 85 centimeters (2.79 feet), upper plane leading. They are joined by two series of 10 oblique struts. A forward equilibrator and a tail-plane element formed by two parallel planes are mounted on a cross-braced fuselage. These two elements are conjugate, constituting thus a secondary control, completely mobile. The tail-plane element forms with the principal planes a V angle, plainly marked.

(1) With an apparatus thus formed, the sustentation for the cell alone is notably greater than for the biplane entire. The tail-plane element, far from aiding in the support, receives on the back the air deviated by the principal planes. It thus reduces the carrying power.

(2) The influence of the two principal parallel planes, separated by a distance sensibly equal to their depth, is evidenced by a loss of carrying power of about 20 per cent of that for the complete but isolated cell. If we denote the total carrying surface of the planes by S, the effective supporting surface of the biplane is $\frac{S.}{1.2}$

(3) The upper plane, in the presence of the lower plane, behaves as though it were isolated. The lower plane, under the influence of the upper plane, loses about one-third of the carrying power of the isolated plane.

In a biplane, the lower plane then operates poorly with regard to carrying power. It may, without inconvenience, be reduced, if such reduction brings other advantages.

(4) For the ordinary angles of incidence, the head resistance of all the parts aside from the principal cell is about 7 per cent of the sustentation. The head resistance of all parts aside from the planes is about 10 per cent of the sustentation.

These values are applicable to biplanes.

(5) The stepwise arrangement of the planes does not give any appreciable advantage with regard to sustentation and head resistance, but renders the construction more difficult.

Such a stepwise arrangement is not, in general, to be recommended.

9. THE AERODYNAMICS OF CURVED AEROFOILS—COMBINATIONS OF CURVED AEROFOILS—AEROFOILS IN TANDEM.

Let us consider two aerofoils of different spread, situated one behind the other (planes in tandem). If the aerofoil with the smaller spread is leading, it is said that the two elements form a "duck"

type. If the aerofoil with the lesser spread follows, it is considered equivalent to the "ordinary monoplane" type.

The angle made by the chords of the two aerofoils in the plane of symmetry is the angle of décalage, or simply the décalage, of one of these planes with relation to the other.

If, in the plane of symmetry, the leading edge of the following plane is in the prolongation of the chord of the leading profile, it is said that the vertical displacement of the two planes is zero.

M. Eiffel has made a series of experiments with two planes of the same type, of which one has an aspect ratio of 6 (90 by 15 centimeters (35.5 by 5.9 inches)) and the other of 3 (45 by 15 centimeters (17.8 by 5.9 inches)).

The "duck" type has been studied (vertical displacement zero) with values of the angle of décalage varying from 2° to 6° and separations of the planes equal to 4/3 and 8/3 their width.

The "ordinary monoplane" type has been studied with a décalage of 4° and separations of the elements identical with the preceding.

Finally, M. Eiffel has studied the tandem type with equal elements.

The angle of incidence of this combination of elements is the angle relative to the chord of the leading element.

(1) **"Duck" type.**

From the viewpoint of sustentation and of head resistance, it is advantageous to increase the separation of the elements, and not to exceed a certain angle of décalage.

Suppose that, for various angles of incidence, there have been determined the total resultants of the air forces on the combination of elements. We shall denote the aggregate of these by the term "bundle of resultants."

In the study of this bundle, the following results are obtained:

(*a*) The bundle is always located toward the middle of the interval which separates the two elements. It is then in this region that the center of gravity of an airplane of this type should be found.

(*b*) For a given distance between the elements, the bundle is so much the more extended as the décalage is greater.

(*c*) For a given décalage, the bundle is so much the more extended as the distance between the elements is greater.

This longitudinal change in the bundle of resultants has relation with the longitudinal stability of an airplane of this type.

(*d*) For a given distance between the elements, the bundle of resultants is displaced toward the forward element in proportion as the décalage is increased.

In an airplane of the "duck" type, if the décalage is increased it is necessary to move the center of gravity forward.

Let us suppose that in such an airplane the center of gravity is on the propeller shaft. For equilibrium under a certain angle of incidence, it is necessary that the resultant corresponding to this angle pass through the center of gravity. From this, let us drop normals on the other resultants of the bundle, resultants which correspond to varying angles of incidence. It is then easy to calculate the moments of these resultants with reference to the center of gravity. These are the stabilizing moments. They are considered positive when they tend to turn their lever arm in direction inverse to the movement of the hands of a watch. They are negative in opposite case.

Let us represent these stabilizing moments by setting off as abscissæ the angles of incidence, and as ordinates the stabilizing moments.

The airplane is longitudinally stable when, for increasing values of the angle, the curve of the moments descends continuously from left to right, cutting the axis of abscissæ at the point of equilibrium. It is unstable when, for increasing angles, the curve of moments rises from left to right.

When study is made of such curves for the "duck" type, it is seen that, from the viewpoint of stability, it is not well to realize too great an angle of décalage for the two elements.

The manageability of the airplane requires also that the décalage shall not be too great, and that the distance between the elements shall also not be too considerable. It is desirable that the stabilizing moments should not exceed 50 kilogram meters (361 pound-feet).

From this same viewpoint it is desirable that the center of gravity of the airplane should not be too low.

M. Eiffel has studied a vertical displacement of the elements approximately equal to one-quarter of the depth of an element. The effect of such a displacement is so little sensible that it may be taken as negligible.

(2) **"Ordinary monoplane" type.**

The influence of the elements, one on the other, is evidenced by a reduction of the sustentation and by an increase in the head resistance in relation to the sustentation and to the head resistance of the elements without mutual action.

The relative diminution of the sustentation is independent of the fore and aft separation of the elements. The resultants are grouped on the forward element. The center of gravity of an airplane provided with such planes must be located in this region.

The bundle of the resultants is opened out considerably when the distance between the elements is doubled.

(3) **Tandem with equal elements.**

From the viewpoint of sustentation and of head resistance, this type is clearly inferior to the "ordinary monoplane" type.

In this last type it is therefore not advantageous to increase, beyond a certain limit, the spread of the tail-plane element.

The biplane arrangement is also preferable to the tandem type with equal elements.

It may be said that this last arrangement is not to be recommended in the construction of apparatus for aviation.

(4) In a tandem, the following element is influenced by the forward element. M. Eiffel has studied the conditions of operation of such an element.

(*a*) If we designate by i_a the angle of incidence of the influenced element to the path of the combination of the elements, the force on this element is equal to the force which would be exerted on the element isolated, for which the angle of incidence would be

$$i_r = i_a - \beta$$

The angle β depends on all the factors which fix the relative positions of the elements, that is to say, on the distance between the elements, on the vertical displacement, on the angular décalage, and on the relative spread of the two elements.

(b) Whatever may be the characteristics of the combination of the elements, the drift of the influenced element is practically equal to that for the same element isolated.

From the viewpoint of the drift, there is no need of distinguishing between the real angle of incidence i_r and the apparent angle i_a.

(c) Whatever may be the characteristics of the combination of elements, the leading element of a tandem behaves like an isolated element.

(d) Case of tail planes.

When the law of variation of the real angles of incidence i_r in relation to the apparent angles i_a is known, and also the values of K_y as a function of the angles of incidence for the isolated tail plane, it is possible to determine the force acting on a tail plane placed behind an ordinary monoplane.

Let us take an example. Consider an ordinary monoplane of which the principal plane has dimensions of 10 by 2 meters (32.8 by 6.56 feet) and the tail element is formed by a plane 3 by 1 meters (9.84 by 3.28 feet) placed 5 meters (16.4 feet) behind the principal plane, with vertical displacement zero. Let us suppose that the angular décalage of the tail element (form V) with relation to the principal plane is 6°. If the normal angle for horizontal flight is 6° (angle of the principal plane with the horizontal trajectory) the apparent angle of the tail plane making a V with the principal plane is zero.

Let us assume that the law of variation of the real angles of incidence as a function of the apparent angles gives $-5.4°$ for the real angle of incidence of the tail plane. The study of the plane gives then $K_y = -0.02$. The force on the tail plane, for a speed of 30 meters (98.4 feet) per second, is $-0.02 \times 3 \times 900 = -54$ kilograms (119 pounds).

Now if the tail plane were isolated and making with the trajectory an angle of zero, the force would be zero. Such a negative force of 54 kilograms (119 pounds) is of the greatest importance with regard to equilibrium.

10. THE APPARATUS OF AVIATION.

M. Eiffel has made, by the fan method, a great number of tests on models of certain forms of apparatus. From these tests we may deduce a certain number of rules, which we shall state at a later point; rules which may serve to establish the preliminary design of an airplane.

The interesting experiments at the Institute of Saint-Cyr on an airplane entire (by means of the car) or on an airplane in free flight are not yet sufficiently numerous to give ground for rules of construction for airplanes. However, these results merit statement.

(1) M. Eiffel has shown fully the use which may be made of a study of the logarithmic diagram for the conditions of operation of an airplane in horizontal movement. It is thus that he has studied the régime of maximum speed for a given power and also the economical régime.

The maximum speed for horizontal flight depends more especially on the engine installed on board the avion (see fig. 3, point i_1).

The economical régime, or régime of minimum power for given weight (see fig. 3, point i_3), is of great interest. In fact, when an avion rises with the maximum vertical speed, it is placed in condi-

tions such that the useful power developed shall be minimum, the excess of power being utilized for raising the airplane to the greatest possible height.

The limiting speeds of an airplane for planing are:

(a) The maximum speed of normal horizontal flight.

(b) The speed corresponding to the minimum slope.

This minimum is defined by the minimum value of $\frac{R_x}{R_y}$. The angle which corresponds to this minimum is the best angle of planing of Col. Charles Renard.

The motive quality or sustaining quality of an airplane introduced by the Constructor Louis Bréguet has for value

$$g = \frac{\rho\sqrt{\frac{Q}{S}}}{\rho\frac{P_M}{Q} - V_m};$$

in which

ρ = efficiency of propeller.

$\frac{Q}{S}$ = weight in kilograms carried per square meter of surface.

$\rho\frac{P_M}{Q}$ = useful work (kilogram-meter-second) of the motor propeller combination per kilogram of weight carried. This power corresponds to the efficiency ρ of the propeller and to the full power P_M of the motor.

V_m = maximum vertical speed in meters per second.

(2) Ordinary monoplanes.

The following coefficients result from the experiments of M. Eiffel.

(a) The loads sustained in relation to the sustaining surface vary between 25 and 35 kilograms per square meter (5.12 to 7.17 pounds per square foot).

(b) The maximum speeds of horizontal flight are comprised between 26.4 and 33.3 meters per second (86.6 and 109.3 feet per second) or 95 and 120 kilometers per hour (59 and 74.6 miles per hour).

The speeds for the economical régime vary between 19.44 and 25 meters per second (63.8 and 82 feet per second) or 70 and 90 kilometers per hour (43.5 and 55.9 miles per hour).

Let us give the name "portance" to the ratio:

$$\frac{Q}{S}\times\frac{1}{V^2}$$

The portance for maximum speed of horizontal flight varies between 0.025 and 0.040. The portance for economical speeds varies between 0.040 and 0.070. The values utilized vary, therefore, between 0.025 and 0.070.

(d) The maximum useful power (maximum horizontal flight) per 100 kilograms (220 pounds) of weight carried varies between 8 and 11 horsepower.

The minimum useful power (economical régime) per 100 kilograms (220 pounds) of weight carried varies between 5 and 6 horsepower.

The useful power expended in raising 100 kilograms (220 pounds) with the maximum vertical speed varies between 1.5 and 6 horsepower.

(*e*) The maximum vertical speeds vary between 2.3 and 4.25 meters per second (7.55 and 13.94 feet per second).

(*f*) Let us assume 6 horsepower per 100 kilograms (220 pounds) for the economical régime.

Let there be an expenditure of 2 horsepower per 100 kilograms (220 pounds) for climbing. This permits of raising 100 kilograms (220 pounds) a distance of 450 meters (147.6 feet) in five minutes.

In a preliminary design we may assume a useful power of 8 horsepower per 100 kilograms of weight carried.

If the propeller has a mean efficiency of 0.70, the power developed on the shaft is $8/0.7 = 11.5$ horsepower per 100 kilograms of weight carried.

In a preliminary design for a monoplane, it is necessary to count on 11 to 12 horsepower per 100 kilograms (220 pounds) of total weight carried, say 120 horsepower for an airplane of which the total weight in flying condition is equal to 1,000 kilograms (2,204 pounds). The consumption per horsepower will be 0.32 to 0.52 kilograms (0.71 to 1.15 pounds) of gasoline and oil, and the weight per horsepower of the engine-propeller equipment, 2 to 3.2 kilograms (4.41 to 7.06 pounds).

(*g*) The minimum values of $\frac{R_x}{R_y}$ are comprised between 0.16 and 0.20.

The best planing angles are comprised between 9° and 11.3° (mean angle = 10°).

The ratios of the limiting speeds for planing are comprised between 1.27 and 1.48.

(*h*) The values of the motive quality are comprised between 0.83 and 1.05.

(3) Biplanes.

(*a*) The loads carried in relation to the carrying surface vary between 15 and 30 kilograms per square meter (3.07 and 6.15 pounds per square foot).

(*b*) The maximum speeds for normal horizontal flight are comprised between 19.44 and 27.8 meters per second (63.8 and 91.2 feet per second), or 70 and 100 kilometers per hour (43.5 and 62.1 miles per hour). The economical speeds vary between 13.9 and 22.2 meters per second (45.6 and 72.8 feet per second), or 50 to 80 kilometers per hour (31 and 49.7 miles per hour).

(*c*) The values of the portance for maximum speeds are comprised between 0.035 and 0.045 and the values for economical speeds between 0.060 and 0.065.

The values utilized lie between 0.035 and 0.065—that is to say, within narrower limits than for monoplanes.

(*d*) The maximum useful power per 100 kilograms (220 pounds) of weight carried varies between 5 and 7 horsepower.

The minimum useful power per 100 kilograms (220 pounds) of weight carried varies between 4 and 5 horsepower.

The useful power expended in lifting 100 kilograms (220 pounds) with the maximum vertical speed varies from 0.5 to 2.5 horsepower.

(*e*) The maximum vertical speeds vary between 0.5 and 1.6 meters per second (1.64 and 5.25 feet per second).

(*f*) Let us assume 5 horsepower per 100 kilograms (220 pounds) minimum useful power and 2 horsepower per 100 kilograms (220 pounds) for useful power required for climbing; it is seen that, for 100 kilograms (220 pounds) of weight carried, there will be required a useful power of 7 horsepower, or a power of 10 horsepower absorbed by the shaft, assuming 0.70 for the mean efficiency of the propeller. This indicates a power of 100 horsepower for an airplane of 1,000 kilograms (2,204 pounds).

For a biplane as compared with a monoplane, there is therefore required less power for the same weight carried.

(*g*) The minimum values of $\frac{R_x}{R_y}$ are contained between 0.142 and 0.228. The best planing angles range between 8° and 11°. The ratios of the limiting speeds of planing are comprised between 1.08 and 1.22.

(*h*) The values of the motive quality are comprised between 0.75 and 1.17.

(4) Hydravions.

(*a*) The loads in relation to the carrying surface vary between 30 and 40 kilograms per square meter (6.15 and 8.19 pounds per square foot).

(*b*) The minimum useful power per 100 kilograms of weight carried is 5 to 6 horsepower for hydravions with floats and 4 to 5 horsepower for hydravions with a boat fuselage.

For the first it is necessary to provide 12 to 13 horsepower (on account of the surface tension which must be overcome as the floats leave the surface of the water) for the power developed by the engine on the shaft per 100 kilograms of weight carried, or 104 horsepower (say an engine of 120 horsepower) for an equipment weighing 800 kilograms. The weight of the engines in flying condition represents about 45 per cent of the total weight of the entire equipment.

For hydravions with a boat fuselage it is necessary to count on 13 or 14 horsepower per 100 kilograms of weight carried for the power developed by the engine on the shaft, or 560 horsepower (two engines of 300 horsepower) for an equipment weighing 4,000 kilograms (weight of engines = 45 per cent of the total weight of the equipment).

(5) Experiments made at the Institute of Saint-Cyr on a Blériot airplane.

At the Institute of Saint-Cyr a study has been made by the car method on a two-passenger Blériot monoplane (side by side). This airplane has a horizontal tail plane in form of V with the main plane, enlarging toward the tail. The characteristics are as follows:

Total spread	11.10 meters	(36.4 feet).
Length	9.00 meters	(29.5 feet).
Area of the planes	25.35 meters^2	(272.9 square feet).
Area of the projection of the fuselage (from its nose to the beginning of the tail plane)	3.27 meters^2	(35.2 square feet).
Area of the tail plane	7.76 meters^2	(83.5 square feet).
Area of the depth rudder	1.68 meters^2	(18.1 square feet).
Angle of the chord of the planes with the tail plane	6°.	

This airplane has been studied between the incidences (angle of the chord of the plane near the fuselage with the horizontal) of $+20°$ and $-2°$ for three positions of the depth rudder, as follows:

(1) Position in the prolongation of the tail plane.

(2) Position of maximum turning downward, the rudder making then an angle of 18° with the tail plane.

(3) Position of maximum turning upward, the rudder making then an angle of 51° with the tail plane.

There is determined, as a function of the incidences, the values of R_x and R_y and the distances from the leading edge of the planes to the point where the resultant cuts the chord of the planes (in the projection on the plane of symmetry of the airplane).

The following results have been obtained:

(*a*) The values of R_x are sensibly the same for all positions of the depth rudder. The propulsive resistance is sensibly independent of the position of this rudder.

(*b*) For a given value of the incidence, the force R_y increases continuously in passing from the rudder position for upward turning to that for downward turning.

The surface of the depth rudder intervenes then in the sustentation.

It should be noted that the quotient $\frac{R_y}{25.35}$ does not exactly represent the portance of the airplane. It is really necessary to take into account the surfaces of the tail plane and of the depth rudder, which, with the variation of the incidence, have incidences positive or negative relative to the horizontal, and thus intervene in a variable manner in the value of the portance.

(*c*) The position of what may be called the center of pressure (intersection of the resistance of the air with the chord) for a given value of the angle of incidence varies much with the inclination of the rudder.

For a given value of this angle, the center of pressure moves continuously from the leading edge as the change is made from the position for turning upward to that for turning downward.

For a given position of the depth rudder, for example, the position in the plane of the tail plane and for near-by positions, the center of pressure moves continuously toward the leading edge for a decreasing incidence, or moves from the leading edge for an increasing incidence. This is the opposite of what takes place with an isolated plane: The variation observed here shows the influence due to the tail plane and the depth rudder.

(6) Study of aeroplane in free flight.

Experiments have been made at the Institute of Saint-Cyr on a Maurice Farman biplane and on a Blériot. If we call S the net carrying surface (17.65 meters^2 (190 square feet) in the Blériot) the quotient $\frac{R_y}{S}$ will measure the portance of the machine.

(*a*) The portance of any avion in volplane flight is less than that in normal flight, when the propeller blast acts on a carrying part of the avion (main plane, tail plane, or supporting tail).

For the Blériot this difference is shown to be 15 per cent.

(*b*) Whenever, in slowing up, the propeller operates as a brake, the head resistance in volplane flight is greater than the head resist-

ance of the avion without propeller. From this action as a brake there results an augmentation of the planing angle.

For the Blériot, fitted with a single screw (diameter 2.45 meters (8.05 feet); pitch, 1.53 meters (5.0 feet), with a rotative speed of 400 to 500 revolutions per minute there has been found 20 to 25 per cent increase in the resistance.

11. PROPELLERS AT A FIXED POINT.

Col. Charles Renard had stated, for propellers geometrically similar, the following law:

$$\text{The ratios } \alpha_0=\frac{\Pi_0}{n^3D^4},\quad \beta_0=\frac{P_e^{(o)}}{n^3D^5} \quad \ldots\ldots\ldots \quad (3)$$

are constant.

Researches undertaken at the Institute of Saint-Cyr have led to the following results:

The coefficients α_0 and β_0 of the formulæ of Renard increase, in general, a little with the rotative speed; however, for certain propellers these coefficients decrease slightly as n is increased, and then increase with further increase of n. The variations in the values of these coefficients are, however, so small that for ordinary values of the rotative speed they may be considered constant.

Col. Renard had also introduced the idea of the quality of a sustentation propeller. This is defined as

$$Q=\frac{\alpha_0^3}{\beta_0^2}\times\frac{4}{0.08\pi}.$$

This quantity depends especially on the pitch of the propeller. It is smaller as the pitch is larger. The product of the pitch by the quality is sensibly constant for propellers geometrically similar.

12. PROPELLERS ADVANCING RELATIVE TO THE MEDIUM.

(1) For propellers geometrically similar, the magnitudes

$$\left.\begin{aligned}\alpha&=\frac{\Pi}{n^3D^4}\\ \beta&=\frac{P_e}{n^3D^5}\\ \rho&=\frac{\alpha\gamma}{\beta}\end{aligned}\right\} \quad \ldots\ldots\ldots\ldots \quad (5)$$

are functions of $\gamma=\frac{V}{nD}$, $\epsilon=nD$, that is to say, of functions of the speed of advance V and of the peripheral speed $\pi\, nD$.

If on two rectangular axes we lay off as abscissæ the values of γ and as ordinates the values, either of α, of β, or of ρ, the points representing the properties of a type of propeller are distributed on curves nD = constant in the planes (α, γ), (β, γ) and (ρ, γ).

However, for large values of V (of the order of 27 to 28 meters (88 to 92 feet) per second (about 62 miles per hour)) and of nD (of the order of 25 to 30), the curves $\epsilon=nD$, corresponding to variations of ϵ of 10 units, are sensibly the same. As these conditions are found

in the values used in practice, we may take for practical purposes α, β, ρ as functions of the quantity γ. In each of the planes (α, β), (β, γ), (ρ, γ) the properties of a given type of propeller may be represented by a single curve.

In the same way the researches carried out at the Institute of Saint-Cyr have shown that, for a wide field of values and comprising the conditions of practice, the ratios $\frac{\alpha}{\alpha_0}$ and $\frac{\beta}{\beta_0}$ are also functions of γ for a given type of propeller.

(2) The ratio $\frac{\alpha}{\alpha_0}$ decreases regularly and quite rapidly as the value of γ increases.

For a given number of revolutions of the propeller, α_0 has a determinate value.

For a given number of revolutions of the propeller, the traction decreases as the speed increases.

(3) In the experiments at Saint-Cyr, the values of $\frac{V}{nD}$ did not exceed 0.90, a value for which $\frac{\alpha}{\alpha_0}$ is not zero. Let us assume it justifiable to extrapolate the curve $\left(\frac{\alpha}{\alpha_0}, \gamma\right)$ to its intersection with the axis of γ, and below this axis. Let us further assume that α_0 has a constant value, whatever may be the revolutions of the propeller. We may then state the following proposition, which, however, is only approximate.

Above a certain value of $\frac{V}{nD}$, the propeller acts as a brake (traction negative); below this value, it acts as a propeller (traction positive).

According to this, the number of revolutions beyond which the propeller becomes propulsive is the greater as the speed V is greater. For a certain propeller of 2.40 meters (7.88 feet) it has been found that as the value of V increases from 4 meters (13.1 feet) per second to 12 meters (39.4 feet) per second, the number of revolutions for which the traction becomes zero passes from 300 to 566.

(4) The values of $\frac{\beta}{\beta_0}$, for a part of the propellers studied, continually decrease with increasing values of γ; for others, $\frac{\beta}{\beta_0}$ first increases slightly with γ and then decreases. In any case, the decrease of $\frac{\beta}{\beta_0}$ is less rapid than that of $\frac{\alpha}{\alpha_0}$.

In considering, as above, what develops for a given velocity of rotation of the propeller, it is seen that the traction Π decreases more rapidly than the power P_e. The latter is, in those conditions, proportional to the couple transmitted to the propeller shaft. The traction and the engine torque are then very far from being proportional.

In the experiments at Saint-Cyr, the point on the axis of γ for which $\frac{\beta}{\beta_0} = 0$ was not determined. As above, let us assume as justified the extrapolation which consists in prolonging the curve $\left(\frac{\beta}{\beta_0}, \gamma\right)$ to

its intersection with the axis of γ. What has just been said shows that this point is farther removed from the origin on the axis of γ than the point of intersection of the curve $\left(\frac{\alpha}{\alpha_0}, \gamma\right)$ with this same axis. When the motive power is zero, the traction is negative and the propeller functions like a windmill. It absorbs power furnished by the air, but does not transmit it to the engine; this power furnished by the air is absorbed by the resistance proper of the propeller, which turns without any manifestation of motive power on the shaft.

(5) For a given number of revolutions, the power absorbed by the propeller at a fixed point is, in general, greater than that absorbed when the propeller moves in the direction of its axis. For the same number of revolutions, it is necessary to supply at the fixed point a greater power than when the propeller advances in the direction of its axis.

For the same power absorbed by the propeller, the number of revolutions of the propeller at a fixed point is, in general, less than that when advancing in the direction of its axis.

Let us consider a propeller put into operation on an airplane at rest. It absorbs a certain power equal to that furnished by the engine. If the airplane is put into motion and if the number of revolutions of the propeller remains constant, the power absorbed by the propeller first decreases, while the power furnished by the engine tends to remain the same. In order that equality may obtain between the two powers, it is necessary that the revolutions of the propeller increase. Thus for a given opening of the throttle valve for the engine, the number of revolutions of the propeller with the airplane in flight is in general greater than when at rest. This increase in the number of revolutions per minute may range from 30 or 40 to 100. For a given engine, certain propellers, giving, with the airplane at rest, a suitable number of revolutions, may in free flight give a number too far above the normal regimen to permit of using such propellers.

In any case, it may be noted that there are certain propellers which require in flight a torque greater than at rest. Instead of speeding up the engine (with fixed throttle opening), they slow it down.

Following are the results of experiments made at the Institute of Saint-Cyr.

Blériot monoplane with Gnome motor, 60 horsepower.

Observations taken in free flight with four Chauvière propellers under the same conditions regarding the engine:

Propeller.	Diameter.	Pitch.	Speed of horizontal flight.	Revolutions per minute.	
				At rest.	In flight.
I.	2.45 meters.. 8.05 feet.....	1.53 meters.... 5.02 feet.......	26.7 meters per second..... 87.5 feet per second........	1,160	1,200
II.	2.40 meters.. 7.90 feet.....	1.75 meters.... 5.75 feet.......	25.6 meters per second..... 84.0 feet per second........	1,130	1,090
III.	2.50 meters.. 8.20 feet.....	1.60 meters.... 5.25 feet.......	25.25 meters per second.... 82.8 feet per second........	1,160	1,300
IV.	2.45 meters.. 8.05 feet.....	1.44 meters.... 4.72 feet.......	27.5 meters per second..... 90.0 feet per second........	1,180	1,220

For the propeller of the greatest pitch there is decrease in the rotative speed; for the other three there is increase in this speed.

From the practical point of view, if in certain cases the number of revolutions of the propeller in free flight is for the same conditions at the motor nearly the same as with the airplane at rest, it must not necessarily be concluded that the power of the engine is decreasing; it may well be that with the propeller employed it can not be otherwise.

(6) The efficiency ρ increases, at first nearly linearly, passes through a maximum, and then decreases rapidly. All propellers have, then, a maximum efficiency corresponding to a determinate value of $\frac{V}{nD}$ peculiar to each type of propeller. This value is nearly independent of nD, at least for the values comprised between 30 and 40 (region of actual practice).

(7) Let us consider propellers which are not geometrically similar. We may say that these propellers form a "group" if the definition of their geometrical form contains a variable parameter with the different values of which they are designed. This parameter may be the pitch, the curvature of the blade, the variation of its width with the distance from the axis, etc. The designer, for example, passes from one propeller to another of the group by preserving the various sections of the blade, but in causing the pitch to vary.

If, then, we consider the propellers of a group differing, for example, only in the pitch, the maximum efficiencies and the corresponding values of $\frac{V}{nD}$ continuously increase with increase in the ratio of the pitch to the diameter.

This was shown by M. le Commandant Dorand in his experiments at Chalais-Meudon on propellers of the same blade area in which the ratio of the pitch to the diameter continuously increased from 0.65 to 1.29.

M. Eiffel has developed the same results on models of the following propellers:

First group: Diameter 0.80 meter (31.5 inches); blades flat on working face; pitch sensibly constant for each propeller; width of blade, 1/10 diameter. At equal distances from the axis the section of the blades is the same. The thickness decreases regularly from the hub to the tip of the blade.

Pitch of propeller.	Pitch ratio.
0.42 meter (16.5 inches)	0.53
.64 meter (25.2 inches)	.80
.78 meter (30.7 inches)	.97
1.04 meters (41.0 inches)	1.30

Second group: Diameter, 0.80 meter (31.5 inches); width of blade, 1/10 diameter; blades hollow on working face. The mean line of the section has a height of segment equal to 1/12 the chord. Pitch constant for each propeller.

Pitch of propeller.	Pitch ratio.
0.42 meter (16.5 inches)	0.53
.65 meter (25.6 inches)	.81
.82 meter (32.3 inches)	1.025
1.02 meters (40.0 inches)	1.26

(8) For propellers of the same pitch and same diameter, but of varying widths of blade, the maximum efficiency passes through a maximum maximorum when the ratio between the greatest width of the blade and the diameter is approximately 1/10.

This ratio has become classical. It is found closely approximate in nearly all propellers.

(9) It is desirable to use a propeller in the vicinity of its maximum efficiency.

In fact, for values of $\frac{V}{nD}$ near the maximum efficiency, the curve (ρ, γ) is, in general, quite flat. It results that, in spite of the variations of regimen of the engine and of the speed of an airplane, the efficiency ρ is always near the maximum. A propeller which does not fulfill these conditions gives only mediocre results.

The practical result of the use of the propeller in the neighborhood of its maximum efficiency is an economy in fuel in horizontal flight, and the possibility of utilizing, more easily and more completely, the excess power of the engine for climbing or in traversing eddies.

Curves (ρ, γ) peaked near the maximum imply a rapid fall in efficiency in case of an acceleration of the engine. The practical consequence is that, in order to obtain a moderate increase in effective power, it is necessary to expend relatively a large amount of fuel and oil, and to risk overstraining the engine.

(10) It is desirable, in practice, in order to have a maximum efficiency high (between 0.70 and 0.80), that γ should be, for such maximum normally near the value 1.0, or equal, say, to 0.90.

In this case, if $nD = 40$, the normal speed of horizontal flight will be equal to 36 meters (118 feet) per second, or 129.6 kilometers (80.5 miles) per hour.

If $n = 16.66$ revolutions per second (1,000 revolutions per minute), $D = 2.40$ meters (7.88 feet). If $n = 20$ revolutions per second (1,200 revolutions per minute), $D = 2$ meters (6.56 feet). If $n = 8.33$ revolutions per second (500 revolutions per minute), $D = 4.8$ meters (15.16 feet).

(11) Some writers have maintained that there is, for each type of propeller, a best value of the ratio of pitch to diameter, characteristic of this type of propeller. This is by no means certain. But it does not appear, as has been sometimes stated, that there is a best value of this ratio for all propellers, value independent of their form.

(12) Propellers have, in general, two or four blades. Four blades should be used in the following case.

Suppose that a propeller is required capable of absorbing a very considerable power. With two blades, there may result:

(*a*) A propeller of too great diameter.

(*b*) A propeller with a speed of rotation too high.

In these two cases, centrifugal force would have a value too high. It would then be advantageous to employ a propeller with four blades which would permit the reduction either of the diameter or of the number of revolutions, that is, to decrease the influence of centrifugal force.

It is necessary that the blades of a four-bladed propeller be designed so that the coefficients $\frac{P_e}{n^3D^5}$ and $\frac{P_u}{n^3D^5}$ shall be as nearly as possible equal to the sum of the values of these coefficients for two

propellers of two blades each, operating each as if alone. This is a matter to be examined specially for each case. Such examination is well adapted to the method by the use of models. It is thus that M. Eiffel has shown, for certain Drzewiecki propellers, that the reduction coming from the influence of the blades in a four-bladed propeller was minimum when the axes of the blades made, between themselves, angles of 75° and 105°.

13. STUDY OF THE MEDIUM SURROUNDING A SCREW PROPELLER.

M. Eiffel has studied, by means of a fan, a certain number of models of screw propellers. He has undertaken to investigate the variation in the velocities of the current air, both in front of and behind a propeller.

The measurements were made in a plane situated, either in front or behind the propeller, at distance equal to 1/5 the diameter.

The velocities were determined (by means of a Pitot tube) at distances from the axis of rotation equal to 1/5, 1/3 approximately, 2/5, 1/2 approximately, and a little more than 1/2 the diameter of the propeller. The next to the last position is near the tip of the blade. The last is a little outside of the cylinder circumscribing the propeller.

Values of $\gamma = \frac{V}{nD}$ are made to vary over a threefold range by varying either V or n, but the former by preference. To these values of γ correspond values of the efficiency ρ.

(1) There is acceleration in the velocity of the current of air, whether in front of or behind the propeller.

(2) The acceleration is greater behind than in front.

(3) Acceleration increases from the hub outward to a distance from the axis between 1/3 and 2/5 the diameter; it then decreases as the tip of the blade is approached.

This decrease is more rapid behind than in front.

(4) The value of the maximum of the acceleration depends on the direction of the relative velocity γ at the tip of the blade. Let γ_m be the value of γ for which the efficiency is maximum. If we then vary from γ_m in the direction of increasing γ, the maximum value of the increase of velocity diminishes; it increases, on the contrary, if we vary from γ_m in the direction of decreasing γ.

(5) The turbulent zone extends very little beyond the cylinder whose base is the circle swept by the tips of the blades. This result shows that the ratio 1/3 adopted between the similar dimensions of a model and the full-sized propeller is sufficient to envelop the model with a surrounding cushion of quiet air sufficiently thick to permit of considering the model as moving in an indefinite mass of air.

(6) The increment of velocity between the forward and rear faces of the propeller is accompanied by a slight contraction in the size of the moving column of air.

(7) The augmentation of velocity due to the propeller has an influence on the operation of an airplane. The sustentation and the propulsive resistance are increased. At the same time this influence does not seem to be very important. Suppose that the blast from the propeller acts on 1/8 of the spread of the airplane and that the increment of velocity is 50 per cent (a rather high value); the mean

velocity of the wind meeting the wing is then increased in the ratio $\frac{7}{8}+\frac{1.50}{8}=1.065$. Such an increment is of no special importance.

(8) These experiments are an illustration of the hypothesis of the "preliminary dynamic condition," due to M. Soreau.

When the propulsive speed of the propeller is less than the circumferential speed of the tips of the blades, as is usually the case, the periodic and rapid movements impressed by the blades on the mass of air surrounding the propeller produce a condition of steady flow. This is characterized by the existence of a fluid vein having the same axis as the propeller which accompanies it in propulsion; this vein remains unchanged so long as the conditions of operation (V, n) remain unchanged. It is in this fluid vein in movement, independent of the position of the blades at any given instant, that the latter operate. M. Soreau gives to this fluid vein the name of "propeller vein."

At the same time there is formed around the blade in movement a sort of fluid prow and stem, on which glide the particles of air in such manner as to constitute a wake, which accompanies the blades without, however, entraining the particles of air. To these wakes or secondary veins, produced in the line of motion of the blades, M. Soreau gives the name of "blade veins."

Taking as a point of departure this hypothesis, M. Soreau has been led to represent certain experiments of M. Eiffel by a formula of the form

$$\alpha=A-B\left[\frac{V+w}{nD}\right]^2 \quad \cdots\cdots\cdots \quad (5)$$

w being the mean axial velocity of the "propeller vein," while A and B are constant for geometrically similar propellers.

Certain experiments of M. Eiffel are well represented by the equation

$$\alpha=0.0196-0.022\left[\frac{V}{nD}+\frac{0.46}{V}\right]^2 \quad \cdots\cdots \quad (6)$$

which may be applied from the value $\frac{V}{nD}=0.3$.

Equation (6) shows that the axial velocity w is of the form

$$w=0.46\,\frac{nD}{V} \quad \cdots\cdots\cdots\cdots \quad (7)$$

In the region of maximum efficiency of the family of propellers considered, γ is comprised between 0.5 and 0.7; w is then comprised between 0.92 and 0.66 meter (3.02 and 2.16 feet) per second. In this region the ratio $\frac{w}{V}$ is then small for values of the speed of propulsion higher than 10 meters (32.8 feet) per second. In this case α becomes a function of γ. Reference has been made above to this fact. The larger the value of V the less distinct are the curves $nD=\epsilon$.

Equation (6) may be written

$$\alpha=0.0196\left[1-\frac{0.022}{0.0196}\left(\frac{V}{nD}+\frac{\frac{0.46}{V}}{nD}\times\frac{1}{nD}\right)^2\right] \quad \cdots\cdots \quad (8)$$

This is of the form

$$\alpha = a\left[1-\left(\frac{V}{\lambda' nD}+\frac{k}{\lambda' V}\right)^2\right] \quad \ldots\ldots\ldots\ldots \quad (9)$$

We should have in the same way

$$\beta = b\left[1-\left(\frac{V}{\lambda'' nD}+\frac{k}{\lambda'' V}\right)^2\right] \quad \ldots\ldots\ldots\ldots \quad (10)$$

The coefficients a, b, λ', λ'', k are constant for propellers geometrically similar, so long as the ratio of similar dimensions does not exceed a certain limit. It does not appear that such relation can be admitted for a propeller and its model when the latter has dimensions too much reduced in relation to those of the propeller.

(9) The ratio 1/3 adopted by M. Eiffel for propellers of airplanes seems to be an upper limit. It leads to rotative speeds of the model of 2,400 and 3,000 revolutions per minute, figures which it seems prudent not to exceed.

When the problem is concerned with the study of the propellers of a dirigible (diameter 4.5 meters (14.75 feet)), this ratio requires the use of models of 1.5 meters (4.9 feet) in diameter. These models seem a little large for the cylinder of air 2 meters (6.56 feet) in diameter employed at Auteuil by M. Eiffel. In this case it would be preferable to employ a model on the scale of 1/4 (diameter, 1.125 meters (3.69 feet)), turning at 2,000 revolutions per minute, corresponding to 500 revolutions per minute for the propellers of the dirigible.

14. INFLUENCE ON THE OPERATION OF A PROPELLER OF A CURRENT OF AIR PERPENDICULAR TO THE AXIS OF ROTATION.

If we call W the velocity of the current of air and if we consider the ratio $\frac{W}{\pi nD}$, the influence on the traction and on the power absorbed seemed to depend on this ratio.

The ratios $\frac{\alpha}{\alpha_0}$ and $\frac{\beta}{\beta_0}$ increase with this ratio, at first very rapidly, then more and more slowly.

These conclusions result from calculations made at the Institute of Saint-Cyr, based on experiments made on small propellers by M. Riabouchinsky, director of the Aerotechnic Institute of Koutchino.

Suppose that for a propeller of the order of size suited for aviation, the action of a wind perpendicular to the axis depends on the relation $\frac{W}{\pi nD}$ in the same proportions as for the small propeller studied by M. Riabouchinsky. We can then estimate the traction which would be realized by a helicopter with vertical axis carried by an airplane in flight.

Suppose a propeller 2.5 meters (8.2 feet) diameter with vertical axis turning at 1,200 revolutions per minute and carried by an airplane with a horizontal velocity of 25 meters (82 feet) per second. The

peripheral speed of the propeller is equal to 157 meters (515 feet) per second and the ratio $\frac{W}{\pi n D}$ has a value 0.16. Referring to the calculations of M. Maurain, director of the Institute of Saint-Cyr, it is seen that the traction of this helicopter would be increased by about 1/3 of its value as a result of the relative current of air due to the movement of the airplane; but the power to be supplied would itself be increased by about 1/4.

It would be interesting to apply such conclusions to the results of experiments on propellers larger than those studied by M. Riabouchinsky.

CONCLUSION.

AERODYNAMIC STUDIES IN FRANCE DURING THE LAST TEN YEARS.

Ten years ago there was only one laboratory in France in which researches on the resistance of air were carried on in a systematic manner. This was the laboratory installed at Chalais-Meudon by Col. Charles Renard. An engineer of great talent and, at the same time, a remarkable scholar, our fellow countryman must be considered as one of the founders of experimental aerodynamics. His studies on the resistance of air upon bodies of different forms and his experiments upon supporting screw propellers have become classic.

Other experimenters had, to be sure, undertaken at this very time interesting researches upon the resistance of the air. We may cite the studies of Marey upon the flight of birds; the experiments with disks in free flight made by the Abbé Le Dantec at the Conservatoire des Arts et Métiers; those of Cailletet and Colardeau upon orthogonal disks thrown from the second story of the Eiffel Tower. Certain engineers, Ricour, Desdouits, Le Grain, Nadal, had taken up the study of the effects of air resistance upon bodies moving at a high rate of speed. But all these tests carried out under unlike conditions were not susceptible of affording a serious basis for studies in aerodynamics and did not furnish engineers with information which was adequate for the carrying through of their designs.

At this epoch they were still teaching in certain engineering schools, regarding the resistance of air upon planes inclined to the direction of the wind, the law of the square of the sine of the angle of incidence, although it had long since been demonstrated that this law, applied to the flight of birds, led to absurd conclusions.

The résumé which we have just made shows the progress which has been accomplished during the past 10 years.

There exist to-day four great laboratories which are chiefly devoted to the study of aerodynamics.

The military laboratory of Chalais-Meudon, under the learned direction of M. le Commandant Dorand, continues the fine traditions of Col. Renard. It is there that the complicated problem of screw propellers is beginning to be cleared up; it is there that important researches upon the gliding flight of avions, and upon the coefficient of safety which should be adopted in the construction of these machines, have been taken up.

M. de Guiche has devoted himself specially to the delicate problem of the distribution of pressure on the wings of airplanes. He has sub-

jected the actions exercised by the air on the surfaces of aerofoils to a minute and precise analysis; he has created a sort of topography of these surfaces which is of the greatest importance for the determination of the laws of areodynamics.

The constructors of airplanes find effective aid in the laboratories of M. Eiffel, at Auteuil, so remarkably well supplied with equipment, and also at the Aerotechnic Institute of Saint-Cyr.

The experiments of M. Eiffel on models have been carried out with the constant purpose of furnishing constructors with coefficients which are reliable. After studying aerofoils, this eminent engineer has devoted his efforts to a precise determination of the influences which these exert upon each other when they are assembled to form actual flying machines. He has determined the relative coefficients for various parts of the avions, the cables and tension wires, the wheels of the landing frames, the fuselage. He has, finally, for the whole apparatus, studied the different conditions of flight.

The question of screw propellers is beginning to be well understood. We know, in particular, what the conditions are under which a model must be tried out in order to give information applicable to a propeller of normal size. The logarithmic diagram proposed by M. Eiffel facilitates the choice of a propeller which will suit a machine of given character.

Parallel with the studies of M. Eiffel on models, the Aerotechnic Institute of Saint-Cyr, under the energetic direction of its director, M. Maurain, and of its subdirector, M. Toussaint, makes use of its elaborate equipment to study avions or parts of avions in normal size. This laboratory, at the present moment the most important in the world, puts at the disposal of inventors numerous pieces of apparatus for measurements which enable them to determine *a priori* the qualities of the machines which they have under design. In collaboration with military aviation pilots, M. Toussaint has been able to install on the avions ingenious registering devices which make it possible to determine, during a flight, the effects of the air on the different parts and the pilot's maneuvers.

This ensemble of researches, executed by the different French laboratories, researches which complement each other, have already led to the series of results of which we have given an idea in Chapter IV of this report. These experimental results derive their importance from this fact, viz, that they have been obtained by means of a large number of careful experiments susceptible of giving them a high degree of reliability.

Aviation has, moreover, derived a great benefit from these laboratory experiments. I will cite here only one confirmatory example. In spite of certain ideas put forward by M. Rateau in regard to screw propellers, the constructors of airplanes made little of the influence of the back of the wings on the value of the supporting force; they believed that the whole effect came from the air pressure upon the face directly exposed to the wind. But certain researches carried out at the laboratory of M. Eiffel on the distribution of air effects on the two surfaces of an aerofoil showed that there were negative pressures on the back and that these were much more important than the pressures on the surface directly exposed to the wind. Wherefore, contrary to the mode of construction in practice, the necessity arose

of fixing solidly the canvas on the back of the wing in order to avoid accident.

The study of the conditions of flight for airplanes by means of registering instruments standardized in the laboratories has, as M. Toussaint has shown, a great importance from the point of view of safety. It is of prime importance to put within the hands of pilots instruments capable of controlling the quality of their evolutions. This is of special importance for the pupil; it is no less so for the experienced pilot. Statistics, in fact, show that a goodly number of accidents are to be imputed to mistakes in piloting. Such false maneuvers are often unconscious and result from the ignorance of the pilot as to the limits of safety in which he can maneuver his avion. By means of appropriate instruments these limits can be determined for each type of machine and even for each machine on the aviation fields by experienced pilots. The rôle of the aerodynamic laboratories is to combine such registering apparatus so as to simplify the installation on board the machines and to standardize these instruments. The Institute of Saint-Cyr has commenced to do this work with success.

Our aerodynamic laboratories are concerned, then, not only with the solving of problems which are a part of the science of aerodynamics but they strive also to come to the assistance of our constructors, and they have their share in the evolution of a weapon which is just now rendering such great services in the war where the destiny of the country which saw its birth is at stake.

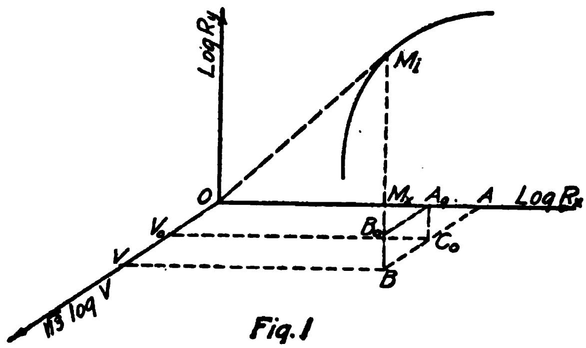

Log R_y
M_1
O
M_x
A_0
A
Log R_x
V_0
B_0
C_0
V
B
1/3 log V

Fig. 1

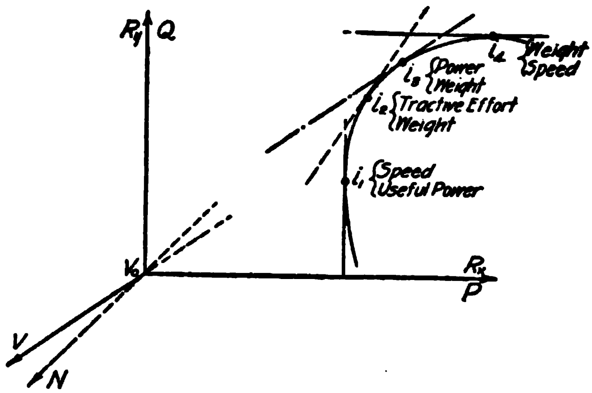
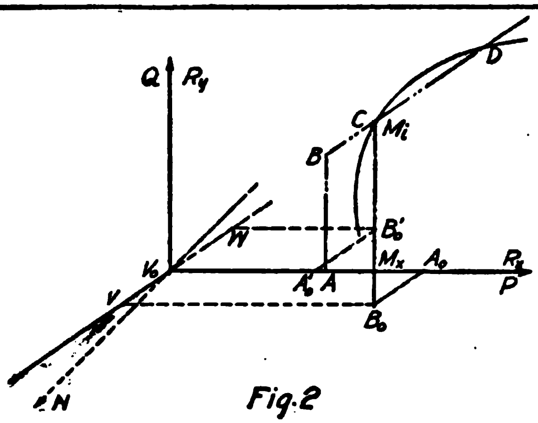
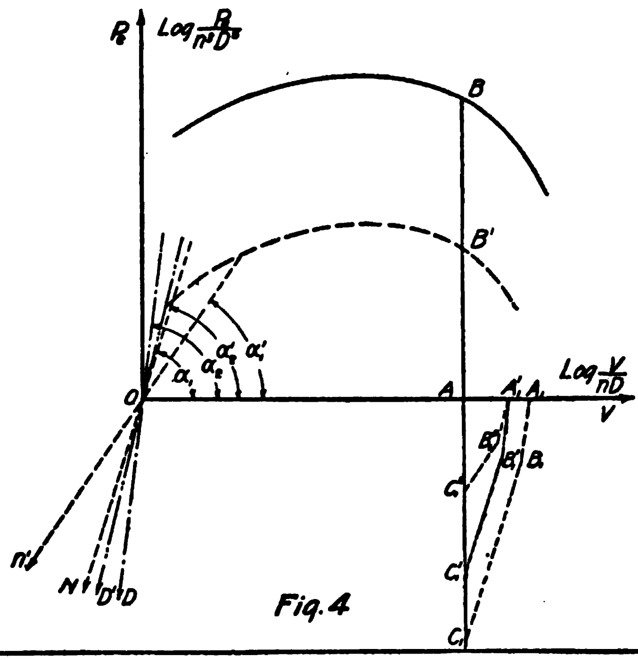

R_y Q
i_4 {Weight / Speed
i_3 {Power / Weight
i_2 {Tractive Effort / Weight
i_1 {Speed / Useful Power
V_0
R_x
P
V
N

Fig. 3



Q
R_y
D
C
M_i
B
B_0'
W
V_0
M_x
A_0
R_x
A_0'
A
P
V
B_0
N

Fig. 2



R_z
$Log \frac{R}{n^2 D^2}$
B
B'
α_1
α_2
α_2'
α_1'
O
A
A_1'
A_1
$Log \frac{V}{nD}$
V
B_1'
B_1
C_1'
C_1
n'
N
D'
D

Fig. 4

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Note.—The works of Col. Charles Renard have been published in the Comptes Rendus de l'Académie des Sciences, in the Revue du Génie Militaire, and in the Revue de l'Aéronautique. References will be found in le Cours d'Aéronautique de la Faculté des Sciences de Paris (L. Marchis), 1ère Partie.